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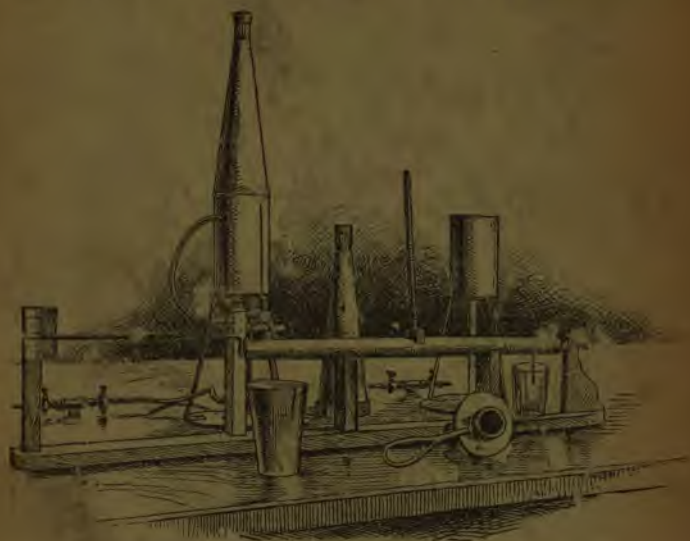
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Teach the pupil, not to believe, but to investigate

PHYSICAL EXPERIMENTS



A Manual and Note Book

Gage

Name

Division

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PHYSICAL EXPERIMENTS

A

MANUAL AND NOTE BOOK

CONTAINING

THE LABORATORY EXERCISES REQUIRED FOR ADMISSION TO
HARVARD UNIVERSITY, AND MANY OTHER EXER-
CISES, AND ADAPTED TO ACCOMPANY
ANY TEXT BOOK ON PHYSICS

BY

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PREFACE.

THIS is simply a laboratory manual. It does not aim to supplant text-book or teacher. Each of these three agencies has its specific function, and neither their three functions nor any two of them can be advantageously exercised by one agent. The manual is prepared with a view to alleviate measurably the difficulties the teacher encounters in consequence of the limitations and necessities incident to a large school, and, furthermore, to economize for actual experimentation the limited time of the pupil. To this end specific directions are generally given for the preparation of notes on experiments, thereby securing uniformity which greatly reduces the labor of the teacher in examining the notes.

The manual is not encumbered with a multiplicity of minute directions for manipulation that may be given *viva voce* by the teacher more intelligibly with the apparatus in hand, nor is it loaded with directions for the manufacture and setting-up of apparatus. It is assumed that the apparatus is in readiness for immediate use when the pupil reaches it, and that he has, at most, but few sentences to read before he commences work.

It is also the aim of this manual to meet the needs of classes in which those pupils who do not expect to pursue their studies further than the high school greatly outnumber those who are fitting for college. It contains nearly all the laboratory exercises required for admission to Harvard University, and many others. The author, having regard for the greater good of the greater number, is accustomed to select for the first year's work from both sets of experiments with reference to the maturity and ability of

the average pupil. During the second or post-graduate year, the pupils (most of whom are fitting for Harvard) devote their time almost exclusively to the Harvard exercises, supplementing the previous year's work in this line.

There are obvious advantages in having the entire history of an experiment, including details of the manipulations, the data and results obtained, question and answer, suggestion and deduction, in immediate conjunction and included between the same covers. Especially is this the case in schools where (as in Boston) the laboratory manuals are retained by the pupil at the end of his course, while the text-books in science remain the property of the city.

For full details concerning the apparatus and its use — especially that used in the Harvard preparatory course — the teacher is referred to Hall and Bergen's "Text-Book on Physics" and Stone's "Experimental Physics." The apparatus called for in this manual can be procured of any general dealer in physical apparatus in the United States.

FORMULAS AND TABLES.



FORMULAS FOR CALCULATING AREAS AND VOLUMES.

$$\pi = 3.1416.$$

$$\text{Area of triangle (altitude } a, \text{ base } b) = \frac{ab}{2}.$$

$$\text{" circle (radius } R) = \pi R^2.$$

$$\text{" surface of sphere} = 4 \pi R^2.$$

$$\text{" " cylinder (hight } h) = 2 \pi R (R + h).$$

$$\text{Volume of sphere} = \frac{\pi D^3}{6}.$$

$$\text{" cylinder or prism (area of base } a, \text{ hight } h) = ah.$$

$$\text{" cone or pyramid} = \frac{ah}{3}.$$



TABLE OF METRIC AND BRITISH EQUIVALENTS.

Measures of Length.

1 in. = 2.540 cm.	1 cm. = .3937 in.
1 ft. = .3048 m.	1 m. = 1.094 yd. = 39.37 in.
1 yd. = .9144 m.	1 km. = .6214 m. (about $\frac{5}{8}$ m.).
1 m. = 1.609 km. = about $1\frac{1}{3}$ km.	

Measures of Surfaces.

1 sq. in. = 6.45 cm ² .	1 cm ² = .1550 sq. in.
1 sq. ft. = 929.03 cm ² .	1 m ² = 1.196 sq. yd.
1 sq. yd. = 25.29 m ² .	1 km ² = .3861 sq. m.
1 sq. m. = 2.59 km ² .	

Measures of Volume and Capacity.

1 cu. in. = 16.387 cc. (or cm ³).	1 cc. = .061 cu. in.
1 cu. ft. = 28.317 dm ³ .	1 m ³ = 1.308 cu. yd.
1 cu. yd. = .764 m ³ .	
1 dm ³ = 1 liter = 1000 cc. = 1.057 American (i.e. wine measure) quarts (about 1 qt.).	
1 American qt. = 32 fluid ounces = .9463 liter.	
1 fluid ounce = 29.571 cc.	1 liter = 61.027 cu. in.
1 gal. (wine measure) = 231 cu. in. = 3.785 liters.	
1 dry quart = 1.101 liters.	1 liter = .908 dry quart.

Measures of Mass.

1 oz. av. = 28.35 g.	1 g. = .03527 oz. av.
1 lb. av. = .4536 k. (about $\frac{5}{11}$ k.).	1 k. = 2.2046 lb. av. (about 2.2 lb.).
1 oz. Troy = 31.1035 g.	1 g. = .02215 oz. Troy.
1 lb. Troy = .3732 k.	1 k. = 2.679 lb. Troy.

1 cu. ft. of water at 62° F. weighs 62.321 lb. av., or about 1000 oz. av.

1 cu. in. of water at 62° F. weighs .036 lb. av.

Pressure in water increases at the rate of about 62.3 lb. per sq. ft., or about $\frac{1}{2}$ lb. per sq. in. for each foot of depth; or at the rate of 1 gram per sq. centimeter for each centimeter of depth; or 1 k. per sq. centimeter for each meter of depth.

Work.

1 erg = 1 dyne-centimeter = .000001 joule = $\frac{1}{778}$ gram-centimeter.
1 ft. lb. = 13562600 ergs = .13825 kgm. = .0012953 lb.-F.
1 kgm. = 7.23314 ft. lb.

Heat.

1 gram-centigrade = .001 kilogram-centigrade.
1 lb.-F. = 772 ft. lb. = 1047.03 joules.

Power.

1 erg per sec. = .000001 watt or volt-ampere.
1 watt = 44.2394 ft. lb. per min.
1 horse-power = 746.941 watts = 42.746 lb. -F. per min.

TABLES OF SPECIFIC GRAVITIES AND DENSITIES.

Solids.

Alum	1.724	Diamond	3.530
Aluminium	2.670	Ebony	1.187
Antimony	6.712	Galena	7.580
Beeswax	0.964	Glass, crown	2.520
Bismuth	9.822	“ flint	3.000 to 3.500
Brass, cast	8.380	Gold	19.360
“ sheet	8.400	Granite	2.650
Camphor	0.988	Graphite	2.500
Cedar	0.554	Ice	0.920
Cherry	0.710	Iron, bar	7.788
Coal, Anthracite	1.300 to 1.800	“ cast	7.210
“ Bituminous	1.260 to 1.400	“ pyrites	5.000
Cork	0.240	Lead, cast	11.360
Copper, cast	8.830	“ sheet	11.400
“ sheet	8.870	Limestone	3.180

Solids. (Continued.)

Magnesium	1.750	Sand, fine	1.520
Maple	0.755	Silver, cast.	10.470
Marble	2.720	Slate	2.880
Pine, white	0.554	Sodium	0.970
“ yellow.	0.461	Sulphur, native.	2.033
Platinum	22.069	Tin, cast	7.290
Potassium	0.865	Walnut	0.680
Quartz	2.650	Zinc, cast	7.000
Rock-salt.	2.257		

Liquids.

Alcohol, absolute	0.800	Nitric acid	1.420
“ common	0.833	Oil of turpentine.	0.870
Bisulphide of carbon	1.293	Olive oil	0.915
Ether	0.723	Sea-water	1.026
Hydrochloric acid	1.240	Sulphuric acid	1.841
Mercury	13.598	Water, 4° C., distilled	1.000
Milk	1.032	“ 0° C., “	0.999
Naphtha	0.847		

Gases.

[Standard: air at 0° C.; barometer, 76 cm.]

Air	1.0000	Hydrogen	0.0693
Ammonia	0.5367	Nitrogen	0.9714
Carbonic acid	1.5290	Oxygen	1.1057
Chlorine	3.4400		

TABLE OF RESISTANCE OF WIRE,

*Chemically pure, one meter long, one millimeter in diameter,
at 0° C. (Jenkin). Also relative resistances (Ayrton).*

		Relative Resistances.
Silver, annealed	.01937 ohm	1.000
“ hard drawn	.02103 “	1.086
Copper, “	.02104 “	1.086+
Zinc, pressed	.07244 “	3.741
Platinum	.11660 “	6.022
Iron, annealed	.12510 “	6.460
Lead, pressed	.25270 “	13.050
German silver	.2695 “	13.92

DIMENSIONS OF WIRE GAUGE SIZES.

No. of Wire Gauge.	Diameter of each No. in decimal parts of an inch of the American Wire Gauge.	Diameter in mm.	No. of Wire Gauge.	Diameter of each No. in decimal parts of an inch of the American Wire Gauge.	Diameter in mm.
0000	.460	11.68	19	.03589	.90
000	.40964	10.40	20	.03196	.81
00	.36480	9.27	21	.02846	.72
0	.32486	8.25	22	.02535	.64
1	.28930	7.35	23	.02257	.57
2	.25763	6.54	24	.0201	.51
3	.22942	5.83	25	.0179	.46
4	.20431	5.19	26	.01594	.41
5	.18194	4.62	27	.01419	.36
6	.16202	4.12	28	.01264	.32
7	.14428	3.67	29	.01126	.29
8	.12849	3.26	30	.01002	.26
9	.11443	2.91	31	.00893	.23
10	.10189	2.59	32	.00795	.20
11	.09074	2.31	33	.00708	.18
12	.08081	2.05	34	.0063	.16
13	.07196	1.83	35	.00561	.14
14	.06408	1.63	36	.005	.13
15	.05707	1.45	37	.00445	.11
16	.05082	1.29	38	.00396	.10
17	.04525	1.15	39	.00353	.09
18	.0403	1.02	40	.00314	.08

TABLE OF TRIGONOMETRICAL FUNCTIONS.

Degree.	Tangent.	Sine.	Degree.	Tangent.	Sine.	Degree.	Tangent.	Sine.
1	.017	.017	31	.601	.515	61	1.80	.875
2	.035	.035	32	.625	.530	62	1.88	.883
3	.052	.052	33	.649	.545	63	1.96	.891
4	.070	.070	34	.675	.559	64	2.05	.899
5	.087	.087	35	.700	.574	65	2.14	.906
6	.105	.105	36	.727	.588	66	2.25	.914
7	.123	.122	37	.754	.602	67	2.36	.921
8	.141	.139	38	.781	.616	68	2.48	.927
9	.158	.156	39	.810	.629	69	2.61	.934
10	.176	.174	40	.839	.643	70	2.75	.940
11	.194	.191	41	.869	.656	71	2.90	.946
12	.213	.208	42	.900	.669	72	3.08	.951
13	.231	.225	43	.933	.682	73	3.27	.956
14	.249	.242	44	.966	.695	74	3.49	.961
15	.268	.259	45	1.000	.707	75	3.73	.966
16	.287	.276	46	1.036	.719	76	4.01	.970
17	.306	.292	47	1.07	.731	77	4.33	.974
18	.325	.309	48	1.11	.743	78	4.70	.978
19	.344	.326	49	1.15	.755	79	5.14	.982
20	.364	.342	50	1.19	.766	80	5.67	.985
21	.384	.358	51	1.23	.777	81	6.31	.988
22	.404	.374	52	1.28	.788	82	7.12	.990
23	.424	.390	53	1.33	.799	83	8.14	.993
24	.445	.407	54	1.38	.809	84	9.51	.995
25	.466	.423	55	1.43	.819	85	11.43	.996
26	.488	.438	56	1.48	.829	86	14.30	.998
27	.510	.454	57	1.54	.839	87	19.08	.999
28	.532	.469	58	1.60	.848	88	28.64	.999
29	.554	.485	59	1.66	.857	89	57.29	1.000
30	.577	.500	60	1.73	.866	90	Infinite	1.000

1.

App.: circular piece of tin about the size of a half-dollar having a radial line scratched upon one of its sides; short metric rule.

(a) Draw a straight line widthwise the blank page. Place the circular tin vertically on the line as near to the left extremity of the line as convenient, and so that the end of the radial line shall touch the ruled line and be perpendicular to it. Make a *very small* point in the ruled line where these two lines meet, and place the letter *a* near this point. From this position roll the tin along the ruled line until the two lines again meet and are at right angles to each other. Locate this point of meeting and letter it *c*. Measure the distance between these two points in millimeters and tenths of a millimeter (dividing with the eye as nearly as practicable). What dimension of the circular tin is this quantity?

(b) Measure the diameter of the tin.

(c) Divide the first of the two numbers obtained above by the last, carrying the division to four decimal places, and state to what decimal place the quotient corresponds with the value of π given on p. v.

(d) What does π represent?

2.

App.: pair of pencil dividers; metric rule.

Draw a circle of 2^{cm} radius.

3.

Calculate the circumference of the circle drawn above.

4.

Calculate the area of this circle (see formula, p. v).

5.

Calculate the area of a sphere having the same diameter as this circle.

6.

Calculate the volume of this sphere.

[To the pupil. In making your records on the blank pages learn to economize space. Place the number of the experiment or exercise centrally as on the printed pages, and write nothing else on the same line with it. Arrange your notes systematically and, so far as practicable, in logical sequence.]

7 [Ex. VII¹].

App.: trip-balance, set of weights, metric rule 30^{cm} long; rectangular block of wood 5 to 4^{cm} long, 4 to 3^{cm} wide, 2.5 to 1.5^{cm} thick.

Get volume, mass, and density of block of wood.—Take four measurements of the length of the block, one at each edge (or one at the middle of each side). Average these to get the average length. Get the width and thickness of the block in the same way.

In measuring apply the division mark 1 (^{cm}) to one edge of the block (*i.e.* do not use the end divisions of the rule inasmuch as they are apt to be worn). Estimate with the eye fractions of a millimeter in tenths. Record measurements in centimeters; thus, 3.47^{cm}.

Record observations and computations as follows:

Dimensions of block of wood.

	Length	Width	Thickness
1 trial	.....	.....	.....
2 “	.....	.....	.....
3 “	.....	.....	.....
4 “	.....	.....	.....
Sum	.....	.....	.....
Average	.....	.....	.....
Volume =	(Indicate mathematical operations.)		
Mass =			
Density =	(Indicate mathematical operation.)		

¹ This indicates the number of the Harvard Exercise to which this experiment corresponds.

8.

App.: metric rule, two rectangular blocks, balance, metric weights, and ball. (State at top of blank page the *kind* of ball used.)

- (a) Measure in centimeters the diameter of the ball as suggested by Fig. 1.
- (b) Calculate the area of its surface in square centimeters (cm^2).
- (c) Calculate its volume in cubic centimeters (cc).
- (d) Find its mass in grams.
- (e) Determine from preceding data the density of the ball.
- (f) What is the density of water?

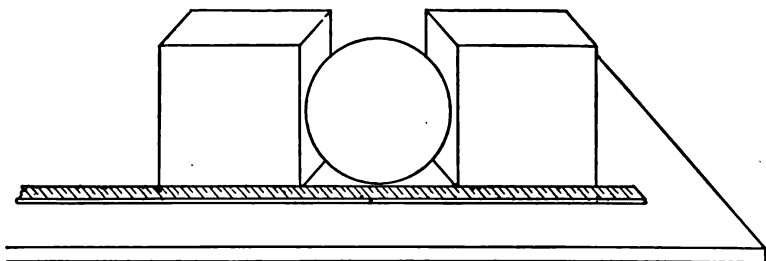


FIG. 1.

- (g) How many times denser is the ball than water?
- (h) What volume of water would have the same mass as the ball?
- (i) If the ball were put into a tumbler brimful of water, what volume of water would run over? What mass of water would run over?
- (j) Which would weigh more, the ball or an equal volume of water? Why?
- (k) Define mass, weight, volume, and density.
- (l) When is weight proportional to mass?

9.

App.: micrometer caliper (Fig. 2), American wire gauge, piece of window glass about 3×2 in., an iron wire 25^{cm} long, balance, and set of weights.

Place the piece of glass in the jaws *B* of the caliper and turn

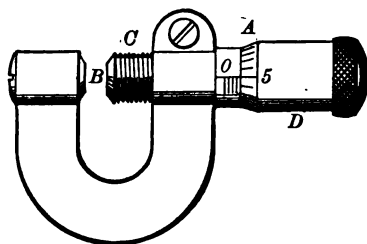


FIG. 2.

the thimble *D* so as to close the jaws and *gently* pinch the glass. Ascertain the thickness of the glass at this point. The pitch of the screw *C* is one millimeter (*i.e.* in one revolution of the screw it advances one millimeter), and the thimble *D* is divided near its end *A* into one hundred parts so as to register

hundredths of a revolution or of a millimeter. Read the millimeters on the scale *O*, and read the tenths and hundredths of a millimeter on the scale *A*, noting the point where the horizontal line *O* (parallel to the axis of the screw) meets the scale *A*. For example, the jaws of the screw in Fig. 2 are open 4.5 millimeters, which is the thickness of any article which would just fill the gap *B*.

Measure the thickness of the glass at five different points at least. Record each result and from these results obtain the average thickness.

10.

(a) With the caliper, measure at intervals of about 3^{cm} the thickness of the iron wire. Ascertain the average thickness of the wire.

(b) Ascertain with the wire gauge the number of the wire which you have measured. State how much greater (or smaller) its diameter is than that given for the corresponding number on p. viii.

11 [Ex. I].

App.: pieces (each about 1^m long) of spring brass wire (No. 27, B. & S. G.), 2 Chattrillon (30-lb.) spring balances graduated to $\frac{1}{2}$ lb., caliper (Fig. 2), sensitive balance for weighing.

(a) [*For two pupils.*] Draw the temper for 3 or 4 in. from each end of a wire by raising it to a red heat in a gas flame. Wind one end upon a cylindrical wooden guard slipped upon a hook of a spring balance and fasten to a tack in the guard. Wind in a similar way the other end upon the guard of the other balance.

Let two pupils pull with the balances steadily and with gradually increasing force, watching the indexes by looking vertically down upon them. Note the reading of the balances when the wire breaks. Care should be taken to avoid friction within the balances. Repeat several times, using other pieces of the wire, taking note only of those breaks that occur between the guards. Record data as follows :

..... wire No.		
Trial	Breaking strength	Average
No. 1		
" 2		
" 3		
	 $\div$ =	

(b) Weigh a measured length (*e.g.* 1^m) of the wire and find its average diameter. Record.

Weight of of the wire g.
Average diameter of the wire mm.

(c) Calculate the length of a piece of the wire that will break by its own weight if suspended at one end.

(d) Calculate the tenacity of the wire in kilograms per square millimeter.

12 [Ex. II].

App.: spring balance (same as in Exp. 11), piece of spring brass wire (No. 27) 4^m long, 2 meter sticks, 2 markers (Fig. 3).

(a) [*For two pupils.*] Slip the two markers upon the wire. Wind one end of the wire twice around a wooden cylinder fixed upon a table and fasten to a tack in the cylinder. Fasten the other end to the hook of the balance. See that neither fastening yields when pulled. Straighten the wire with a horizontal pull of 1 or 2 lb. and fasten the markers near each end of the wire. Measure the length of wire between the markers. Place a meter stick opposite each

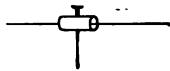


FIG. 3.

marker and, starting with the original pull of 1 or 2 lb., note how much the wire is stretched between the markers by an additional pull of 1 lb. Both markers will move and the difference between the movements will measure the amount of stretching between them. [It is advisable to place beneath each marker a small glass mirror, and in taking readings to place the eye in such a position that the marker will hide its own image.]

Reduce the pull to the original 1 or 2 lb., and note whether the wire resumes its original length as shown by the return of the markers to their former positions.

Make a series of such tests, starting always with the original 1 or 2 lb. and increasing the force 1 lb. each time until the wire becomes *strained* beyond its limit of recovery, *i.e.* until its "limit of elasticity" has been exceeded.

In recording results, do not count the force (1 or 2 lb.) applied to keep the wire straight.

DATA.

Tension in lb.	Total elongation in mm.	Permanent elongation in mm.
.....		
.....		
etc.	etc.	etc.

RESULTS.

Temporary elongation in mm.	Total elongation per lb. tension in mm.	Ratio of total elongation per lb. to length of wire.
.....		
.....		
etc.	etc.	etc.

(b) State what relation, if any, exists between the temporary elongation (or strain) and the tension.

(c) What is the ratio of the tension when perfect elasticity fails to the breaking strength of the wire?



13 [Ex. III].

App.: 2 rods of clear white pine of like grain, one $41 \times 1 \times .5$ in., the other $41 \times .5 \times .5$ in.; 3 triangular prisms of wood 1 in. thick, a scale 10^{cm} long graduated in mm., a light indicator rod about 32^{cm} long, scale pan for weights, and weights 100^{g} to 2^{kg} .

(a) Place the narrow rod and other apparatus in position as in

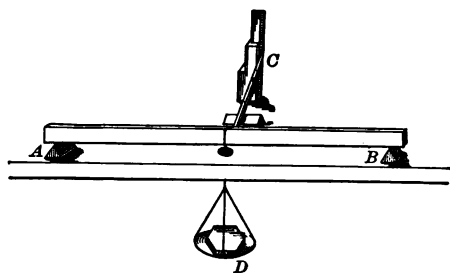


FIG. 4.

Fig. 4, the upper edges of *A* and *B* 1^{m} apart. The indicator *C* is placed halfway between *A* and *B* and adjusted so that its arms may have an exact ratio, e.g. $5:1$. Read the position of the indicator on the scale. Place 100^{g} in the pan *D* (this added

to the weight of the pan constitutes the load) and read again. Next add 100^{g} to the present load and read again. Repeat, increasing the load 100^{g} each time till permanent bending is observed on removing the weight or until a load of at least 500^{g} has been used. Record as follows:

DATA AND RESULTS.

LOAD.	READINGS WITH LOAD.	READINGS WITHOUT LOAD.	MEAN READING WITHOUT LOAD.	RISE OF POINTER ON SCALE.	DEFLEC. OF ROD.	DEFLEC. PER 100^{g} .
g.	cm.	cm.	cm.	cm.	cm.	cm.
0		3.00				
100	3.40	3.00	3.00	$.40 \div 5 =$	.08	.08
200	3.75	2.98	2.98	.77	.154	.077
.....						
.....						
.....						
Mean						.....

(b) Use the same rod with supports 50^{cm} apart. Proceed exactly as in (a), beginning, however, with 500^{g} and increasing 500^{g} each time to 2000^{g} . Record as before.

(c) Use the wide rod flatwise on supports 1^m apart. Load with 200^g and increase 200^g each time to 800^g and experiment and record as before.

(d) Use the same rod edgewise on supports 1^m apart. Commence with 500^g increasing 500^g each time to 2000^g. Record as before.

(e) (1) What is the relation between the transverse force applied and the flexure of elastic rods? (2) What, between length of rod and flexure? (3) What, between breadth of rod and flexure? [In considering these relations, the pupil should be certain that all the conditions are the same except the one in question.]

(f) Show how closely your results agree with the law, *Flexure varies inversely as the cube of the thickness of the rod, i.e. flexure $\propto \frac{1}{t^3}$.*

14 [Ex. IV].

App.: 2 rods of ash, each 1 yd. long, one $\frac{1}{2} \times \frac{1}{2}$ in., the other $\frac{3}{4} \times \frac{3}{4}$ in. in cross section; [one end of each rod is fitted into a circular board 1 ft. in diameter, the other is clamped between two horizontal boards, *A* (Fig. 5); a cardboard, *B*, containing a scale of degrees rests upon the table just outside the circular board;] 2 8-oz. and 2 30-lb. spring balances.

Elasticity of torsion. [For two pupils.] Clamp the small rod in

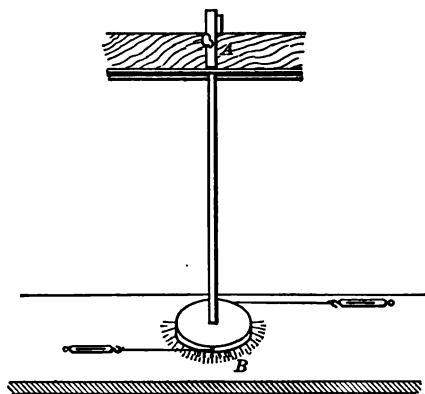


FIG. 5.

a vertical position so that the circular board will just clear the table, leaving 80^{cm} of the rod between the support and the circular board, and so that a pin in the circumference of the board will point to 0° on the scale. Having attached the 8-oz. spring balances as in Fig. 5, pull horizontally in opposite directions, changing the direction of the pull as the rod twists so that

the pulls will be kept at right angles to a line connecting the points where the strings are attached.



(a) Pull successively with forces of 2, 4, 6, and 8 oz. and note the resulting torsion in degrees. Record as follows:

DATA.		
Pull.	Torsion.	Torsion per oz.
2 oz.	°	°
4 "	°	°
6 "	°	°
8 "	°	°

(b) Clamp the small rod so as to leave only 40^{cm} to be twisted. Repeat (a) but use this time forces of 4, 8, 16, and 32 oz. Record as in (a).

(c) Repeat (a) with 80^{cm} of the large rod, using forces of 1, 2, 3, and 4 lb.

(d) Repeat with 40^{cm} of the large rod and forces of 2, 4, 6, and 8 lb.

Conclusions.

(e) Divide each number in the first column of (a) by the first number (2); also divide each number in the second column by the first number in that column, and from the results thus obtained state any relation that you may discover between the force applied and the torsion produced.

(f) Find the average torsion of rod per ounce in (a); also in (b). Divide the former by the latter. Divide the length of the rod in (a) by the length of the rod in (b).

Are the quotients equal or nearly equal?

Can you state a probable relation between the torsion for equal forces and the length of rods?

(g) Divide the average torsion per ounce in (a) by the average torsion per ounce in (c); also diameter of the rod in (a) by the diameter of the rod in (c).

Show how nearly your results agree with the law, $\text{torsion} \propto \frac{1}{d^4}$, where d is the diameter of the rod.



15.

App.: glass flask with stopple, through which passes a glass tube reaching nearly to the bottom of the flask. The tube projects above the stopple about 3 in., and is drawn out so as to allow only a very fine stream to pass through it.

(a) Put water into the flask so as to cover the end of the tube about an inch. Blow into the bottle through the tube all the air possible from the lungs, and cover the end of the tube with the tongue to prevent the escape of air. When ready, withdraw the tongue. What happens?

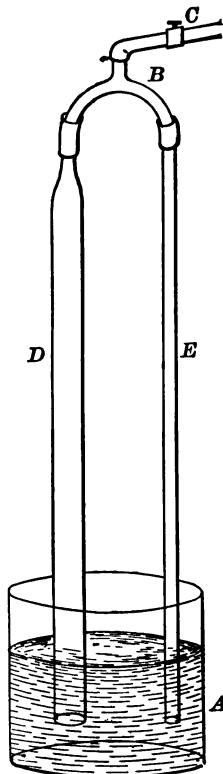


FIG. 6.

(b) What property does this phenomenon show that air possesses?

(c) Is it the weight of the air in the flask that causes the water to escape, or is it the elastic force of the air due to its compression?

(d) When the stream ceases, does the water in the tube settle to the level of the water in the flask?

(e) Where is the expansive force of the air greater now, inside or outside the flask?

(f) Estimate the difference in pressure of the two airs per square centimeter, reckoning 1^s for every centimeter the water surface in the tube is higher or lower than the water surface in the flask. [Find by inserting the tube in an open vessel of water what allowance should be made, if any, for capillary action.]

16.

App.: glass Bunsen battery cup, *A* (Fig. 6), partly filled with water; glass T-tube, *B*, with rubber tube and clamp, *C*. Connected with the T-tube by rubber connectors are a glass tube, *E*, of small bore, and a tube, *D*, of large bore, but drawn out small at its upper end.

(a) *Is the height of a column of liquid which atmospheric pressure sustains dependent on the size of the column?*

Thrust the tubes into the water and suck some air out, and clamp the rubber tube at *C*. Conclusion, and how reached.

(b) *Is the height of the barometric column dependent upon the size of the bore of the barometer tube?*

17 [Ex. V¹].

App.: hydrometer jar about 15 × 2 in. containing water, a meter stick, a bent glass tube containing mercury in the U-bend.

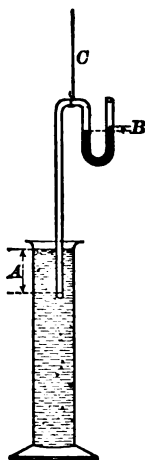


FIG. 7.

(a) Thrust the long arm of the tube into the water to a depth of about 10^{cm}. Measure the vertical distance *A* (Fig. 7) between the two water surfaces; also the vertical distance *B* between the two mercury surfaces.

Thrust the tube down to about half the depth of the jar and make similar measurements of new distances *A'* and *B'*. Finally thrust the tube down as deep as possible and measure distances *A''* and *B''* (Fig. 8). Record as follows :

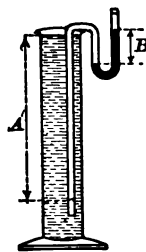


FIG. 8.

Depths.	Pressures.
<i>A</i> = ... cm.	<i>B</i> = ... cm.
<i>A'</i> = ... "	<i>B'</i> = ... "
<i>A''</i> = ... "	<i>B''</i> = ... "

(b) Test the proportionality between the numbers representing the different depths in the water and the numbers representing the corresponding pressures; i.e. is $A : A' :: B : B'$? Record as follows :

(<i>A</i>)	(<i>A'</i>)	(<i>B</i>)	(<i>B'</i>)	(<i>A'</i>)	(<i>A''</i>)	(<i>B'</i>)	(<i>B''</i>)
.....							
(<i>A</i>) × (<i>B'</i>)	(<i>A'</i>) × (<i>B</i>)	(<i>A'</i>) × (<i>B''</i>)	(<i>A''</i>) × (<i>B'</i>)				
... (=, >, <) ...	... (=, >, <) ...	... (=, >, <) ...	... (=, >, <) ...				

(c) If the foregoing quantities are approximately proportional, then frame a law which will express the relation, thus: *The upward pressure in a body of liquid varies, etc.*

(d) What does the water in the tube press against, and in what direction does it press ?

(e) What transmits the pressure to the mercury ?

(f) What represents the magnitude of this pressure ?

¹ Exps. 17 and 18 are substitutes for parts of Ex. V.

18 [Ex. V].

App.: 2 prisms of light paraffined wood of about the following dimensions: one 7^{cm}, the other 14^{cm} long, and both 2^{cm} square; each has a bore 15^{mm} in diameter extending nearly through it, and is stoppled at the open end, and each has a centimeter scale along its length; some bird-shot, jar of water, metric rule, balance, and weights.

(a) Make suitable measurements with great accuracy, and calculate the area of a cross section of each prism.

(b) Place in the short prism 15 to 25 shot¹ and stopple it. Weigh the whole. Place the closed end in water and measure the depth to which it sinks, dividing (with the eye) to tenths of a centimeter making suitable allowance for the turning up of the water against its sides.

(c) Wipe the prism dry, introduce a few more shot (enough to sink it probably to within 1^{cm} of its top) and repeat (b).

(d) Place in the long prism 30 to 40 shot and proceed as in (b). Add more shot several times and proceed as in (c).

Since the prisms are supported by the water, it is evident that the water must exert upon the bottom of each prism a pressure equal to its own weight. Calculate in each case the pressure per square centimeter (cm²), and record as follows:

Weight of prism in g.	Pressure per cm ² in g.	Depth in cm.
.....		
.....		
etc.	etc.	etc.

(e) State your conclusion as to the relation between the pressure and the depth.

(f) What is the pressure at the depth of any given number of centimeters in water?

(g) At what depth in water is the pressure one kilogram per square centimeter?

¹ Use only enough shot to cause the prism to assume an upright position in the water.



19 [Ex. V].

App.: jar of water, rectangular block of wood, *B* (Fig. 9), narrow glass jar (e.g. measuring graduate), *A*, bent glass tube, *C*.

- (a) The jar *A* is filled with water and inverted. With the apparatus arranged as shown in Fig. 9, carry the tube *C* from side to side of the large jar, keeping the lower bend always in the same horizontal plane *ab*, sometimes bringing the open end of the tube under *A*, sometimes under *B*, and sometimes under neither.

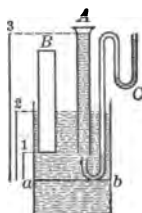


FIG. 9.

The different depths of water over the tube at different places are represented by the lines 1, 2, and 3. Observe whether the pressure as indicated by the water in the bend at *C* changes with these

changes in depth.

- (b) State your conclusion as to whether the pressure at all points in a horizontal plane passing through a liquid at rest is the same regardless of the depth of water immediately over the several points.

20 [Ex. VI].

App.: Boyle's tube (Fig. 10), mercury, meter stick, and barometer. [A meter stick, with indicator (Fig. 11), supported by a base block is a very useful instrument in making these and many other measurements of vertical distances.]

(a) *Boyle's Law.* Let mercury be either at the same level, AB , in both arms of the tube or a little higher in the open arm than in the closed arm. The body of air to be experimented with is imprisoned in the closed arm between A and C . The dimensions of this body can vary only in height; hence its height (*i.e.* the distance between the surface of the mercury in this arm and the top of the bore) may represent its *volume*. The pressure (or expansive force) of the air is evidently represented by the height of the barometric column of mercury plus the vertical height of B , B_1 , etc., above the surface of mercury in the closed arm.

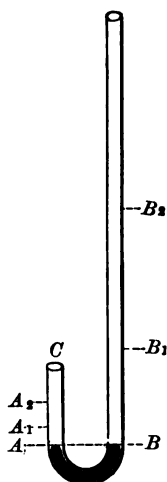


FIG. 10.

Let B = barometer reading.

Let A = vertical distance from baseboard to top of bore in short arm.

Let S = vertical distance from baseboard or table to top of mercury in short arm.

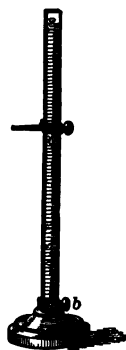


FIG. 11.

Let T = vertical distance from baseboard to top of mercury in long arm.

Let V (*i.e.* $A - S$) = the volume of confined air.

Let P' = vertical distance between the two surfaces of mercury ($T - S$) or the column of mercury which represents the excess of the pressure above an atmospheric pressure.

Let P = total pressure ($B + P'$).

Obtain and record data as follows, adding mercury from time to time so that the surfaces of the two arms will appear at different elevations as A_1 , B_1 , A_2 , B_2 , etc.:

	A	S	$B = \dots \text{cm.}$	T	V	P
1	 cm.	 cm.	 cm.	 cm.	 $\times$	 = ...
2	 "	 "	 "	 "	 $\times$	 = ...
3	 "	 "	 "	 "	 $\times$	 = ...

(b) What relation between the volume and pressure of a body of gas do your results indicate?



21.

App.: tall, narrow, glass jar (Fig. 12), straight glass tube and rubber stopple, ring stand and clamp to hold the tube, mercury, meter stick, and barometer.

- (a) *Boyle's Law; pressures less than one atmosphere.* Push the tube, open, nearly to the bottom of the jar containing mercury, close *tightly* with the rubber stopple, and raise it till the mercury inside the tube is on a level with the mercury outside. Clamp the tube in this position.

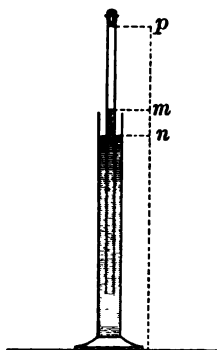


FIG. 12.

Measure the length of the air column in the tube. Raise the tube somewhat and measure the heights p , m , and n above the table. Then the volume of the body of air in the tube is proportional to $p - m$, and the pressure of the air is $b - (m - n) = (b + n - m)$, where b is the height of the barometer column.

Make several determinations, raising the tube several times. Record as follows :

DATA.

p	n	m	$p - m$	b	$b + n - m$	$(p - m)(b + n - m)$

- (b) State your conclusion (and how it is reached) as to whether Boyle's Law is applicable in case the pressures are less than one atmosphere.



GRAPHICAL METHOD OF REPRESENTING VARYING QUANTITIES.

Suppose that we have two quantities, x and y , which are related to each other and vary together; for example, let x represent the interest, compound or simple, on a sum of money for a term of y years. Take a piece of coördinate paper (Fig. 13) divided into

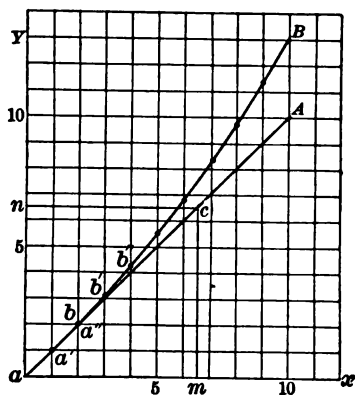


FIG. 13.

squares by equidistant vertical and horizontal lines. Select one of each of these lines to start from. The vertical line is called the *axis of Y*, and the horizontal line the *axis of X*, and their intersection the *origin*. Take point a as the origin, and let the horizontal spaces to the right represent the number of years, and the vertical spaces multiples of the first year's interest; then points a' , a'' , a''' , etc., represent the interest at the end of the first, second, third, etc., years. Connect these points by a straight line aA . Now, if we take any point, as c , in this line, and connect it with the axis Y by a horizontal line nc , and with the axis X by a vertical line mc , the former will represent the time and the latter the interest which has accrued at that time. The line nc is called the *abscissa*, and the line mc the *ordinate* of the point c . Generally distances along the axis of X are *abscissas*, and distances along the axis of Y are *ordinates*.

In a similar manner are found points b , b' , b'' , etc., representing the *compound* interest at the end of the second, third, and fourth years. Having connected these points by the curved line aB , the ordinate of any point in this line will represent the compound interest which has accumulated at the time represented by its abscissa. Such a curve furnishes a most convenient and ready way of investigating the relation of one of two mutually varying quantities to the other. What does the point A represent? the point B ? the line AB ?



22.

App.: coördinate paper.

(a) Draw a line to represent the relation between the volumes and the pressures obtained in the various observations of Exp. 20. Choose a point of origin near the lower right-hand part of the coördinate paper. Take the numbers in the columns under the letters V and P . Let (say ¹) one of the divisions of the axis of X represent five units of pressure (5^{cm}); locate upon this axis the first pressure. Let (say) five divisions of the axis of Y represent one unit of volume; locate upon this axis the first volume. Proceed in like manner to locate upon these axes the second, third, etc., pressures and the corresponding volumes. Imagine vertical lines to be drawn from each of the points thus located in the axis of X to meet imaginary horizontal lines drawn from the corresponding points in the axis of Y . Place points where these imaginary lines would intersect. Having located a series of points representing the successive magnitudes of pressure and volume, through these points draw an evenly flowing curve, or, if this is impracticable, draw a curve through the average of the points so as to show a *mean* of the observations.

(b) Assume some pressure and find the volume corresponding to the assumed pressure.

(c) In like manner construct a curve to represent the relation between the volumes ($p - m$) and the pressures ($b + n - m$) obtained in Exp. 21.

¹ The magnitude of the numbers to be represented and the conditions of the experiment must determine what scale shall be adopted in any given case.



25.

App.: balance (Fig. 15), metric weights, tumbler of water, graduated (in mm.) cylinder partly filled with water, pebble stone that can be placed in the cylinder.

(a) Weigh the stone in air. Weigh it in water, suspended as in Fig. 15. Find how much weight it loses when weighed in water. Why does it weigh less in water?

(b) Place the graduate containing water on a horizontal surface and read the volume of water. [In making these readings wrap a piece of paper around the graduate and bring the edge of the paper on a level with the lowest point of the *meniscus* or curved surface of the water. In order to do this exactly, the eye must be brought to the level of this point. An error due to a failure to read a scale with the line of sight in the proper position is called an error of *parallax*.] Drop the pebble into the graduate and again read the volume. Calculate the increase of volume. In your opinion, does this increase of volume represent the volume of the stone?

(c) Compare numerically the loss of weight (in grams) of the pebble when weighed in water with its volume in cubic centimeters, and state your conclusion as to the relation between the loss of weight of a body immersed in water expressed in grams and its volume expressed in cubic centimeters. [Make a full generalized statement of the important fact.]

(d) In which direction, upward or downward, is the pressure of the water against the pebble greater?

(e) How much greater is one of these pressures than the other? Why is one pressure greater than the other?

(f) In which medium, water or air, can you lift a body of the greater mass?

26 [EX. VIII].

App.: balance with hook under one of the pans, set of weights from 20^g to 1^g, tumbler of water, and small bodies (3 to 6^{cc}) of various substances.

From the hook beneath the scale pan (Fig. 15) suspend by a fine thread a small body of a substance whose specific gravity is to be found, and weigh it, while dry, in the air. Then immerse the body in a tumbler of water (do not allow it to touch the tumbler, and see that it is completely submerged) and weigh it in water. While weighing, use the left hand to steady the balance beam on its support, and to prevent the pan from touching the water beneath. Record at the top of the page the weights in grams and hundredths of a gram as soon as found.



FIG. 15.

Indicate below the mathematical operations, and still lower on the page tabulate the results. The arrangement is as follows :

	Wt. in air	Wt. in water	Loss
Quartz			
Marble			
Zinc			

$$\text{Sp. gr. of Quartz} = \frac{\text{.....}}{\text{.....}} = \text{.....}$$

$$\text{“ “ Marble} = \frac{\text{.....}}{\text{.....}} = \text{.....}$$

$$\text{“ “ Zinc} = \frac{\text{.....}}{\text{.....}} = \text{.....}$$

	Sp. gr. as found	Sp. gr. as per table (pp. vi and vii)	Difference
Quartz			
Marble			
Zinc			



27 [Ex. IX].

App.: rectangular block of wood such as used in Exp. 7, piece of sheet lead about $1\frac{1}{2}$ in. long and $\frac{1}{2}$ in. wide to be folded about the block of wood for a sinker, balance, weights, metric rule, tumbler of water.

Obtain and record data as follows:

I.

Dimensions of block of wood: length, width, thickness

Volume = ... $\times$ $\times$ = ... cc.; mass = ...; density of wood = ... $\div$ = ...

II.

Wt. dry block in air	Wt. water displaced by block
" " sinker "	Sp. gr. of the block = . . . $\div$. . . = . . .
" sinker in water	Density of wood = ...
" water displaced by sinker	Difference of density as found by the
" block and sinker in water	two methods
" water displaced by both	Sp. gr. of lead = . . . $\div$. . . = . . .

28.

App.: specific-gravity bottle and counterpoise (Fig. 18), balance, weights, distilled water, and some granular or friable matter, *e.g.* dry sand, clay, earth, etc.

Weigh a portion of the given solid, enough (say) to about one-fourth fill the bottle; make a conical-shaped tunnel of paper that will just fit the neck of the bottle; pour the matter into the bottle and fill the bottle with water; place the bottle on one scale pan and its counterpoise on the other, and weigh the contents of the bottle. The difference between this weight and the sum of the weights of the solid and the water which the bottle is capable of holding is the weight of the water displaced by the solid. Compute the specific gravity of the solid.

29 [Ex. X].

App. as shown in Fig. 16, consisting of a three-way glass tube, *A*; 2 glass tubes, *B* and *C*, each about 2 ft. long; 3 short pieces of rubber tubing, two of which are used for connectors, and one is applied to the free end of *A*; 2 tumblers, one containing water, and the other a liquid (*e.g.* kerosene) whose density is to be compared with that of water; a clamp, and a measuring stick.

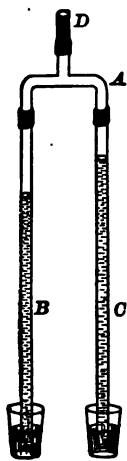


FIG. 16.

(a) Introduce the tubes *B* and *C* into the two liquids, suck air from the extremity *D* until one of the liquids has risen nearly to one of the rubber connectors, then clamp the rubber tube *D* so that air cannot enter. Measure the elevation of the liquid in each of the tubes *B* and *C* above the surface of the liquids in the tumblers.

(b) How is the liquid in the two tubes sustained?

(c) Why is the liquid in one tube raised higher than that in the other?

(d) What relation is there between the densities of the two liquids and the heights to which they are raised by equal pressures?

(e) Compute the specific gravity of the kerosene.



30.

App.: demonstration hydrometer, *H* (Fig. 17), consisting of a prism of paraffined wood, $\frac{1}{4}$ in. square and 5 in. long, with inch and quarter inch divisions, and loaded so as to assume a vertical position when placed in a liquid; beaker of water, and beakers of other liquids, each beaker having a label with the name of the liquid on it.



FIG. 17.

(a) Lower *H* into water: it sinks to the number 4, displacing how many cubic inches of water?

(b) Rinse *H* with water, wipe, and lower it into one of the other liquids. Note carefully the depth to which it sinks, dividing with the eye each division into quarters (sixteenths of an inch). What volume of this liquid does *H* displace?

(c) Is this liquid denser or rarer than water?

(d) What relation exists between the volumes of the liquids displaced by a floating body and their densities?

(e) Calculate the specific gravity of the liquid last used.

31.

App.: balance (Fig 18), specific-gravity bottle filled with some liquid whose specific gravity is sought, counterpoise of the empty bottle, and weights.

Place the bottle on one of the scale pans, and on the other pan the counterpoise. Find the weight of the liquid in the bottle. The weight of an equal volume of water is engraved on the bottle. Find the specific gravity of the liquid.

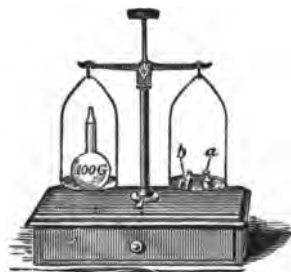


FIG. 18.

32.

App.: tumbler nearly full of a liquid (*e.g.* solution of common salt, saltpetre, etc.) whose specific gravity is sought, another tumbler to be nearly filled with fresh water, small pebble (*e.g.* quartz), balance (Fig. 15), and weights.

(a) Find the loss of weight of the pebble when submerged in the given liquid. Rinse the pebble in clean water, wipe it, and find its loss of weight when submerged in water. From these data determine the specific gravity of the given liquid.

(b) Find the volume of the pebble. [See (c), Exp. 25.]



33 [Ex. XI].

App.: air pump, 2-qt. bottle with perforated rubber stopple through which passes a glass tube extending almost to the bottom of the bottle and projecting about 3^{cm} above the stopple, rubber tube about 30^{cm} long to fit glass tube, clamp, trip balance, and weights, jar of water.

(a) Weigh collectively the bottle, tubes, stopple, and clamp. Connect with the air pump and exhaust the air in the bottle as much as practicable. Clamp the rubber tube near the pump. Weigh the whole again, and ascertain the weight of air removed.

Plunge the clamped end of the tube into the jar of water and loosen the clamp. See that when the water ceases to flow into the bottle the surface of the water in the bottle is on the same level with the water in the jar. Tighten the clamp, raise the bottle from the water, loosen the stopple and clamp, and allow the water in the tube to run into the bottle. Weigh the whole again including the water.

Pour water into the bottle so that, with the stopple in place, it shall be full of water. Weigh the whole again and ascertain the weight of water which the stoppered bottle holds. Record as follows :

DATA.

Wt. of bottle (etc.) full of air, a , = ... g
 " " " after exhaustion, b , = ... g
 " air exhausted ($a - b$) = ... g
 " " with water, etc., d , = ... g
 " water admitted ($d - b$) = ... g
 " " which fills the bottle g

RESULTS.

(b) Assuming that the admitted water replaces volume for volume, at the atmospheric pressure, the portion of air that was exhausted, find the specific gravity of the air referred to water as a standard.

(c) Evidently the ratio of the two weights of water shows the ratio of exhaustion. Ascertain the "degree of exhaustion" expressed as a per cent.

(d) When the water ceased to flow into the bottle, the surfaces of the water in the bottle and the jar being on the same level, how did the pressure of the air in the bottle compare with the atmospheric pressure? Explain.







36.

App.: protractor, metric rule.

Two forces, capable of giving to a certain mass velocities respectively of m.¹ and m. per second, act on that mass at an angle of°. Determine the resultant velocity and its direction (expressed in degrees) relative to that of each component. Indicate the directions of all velocities by arrowheads inserted in the lines representing the velocities. Use a scale of 1:200. Record as follows:

Resultant velocity m. per second.
Angle of resultant with larger component°
“ “ “ smaller “°

37.

Resolve a velocity of m. per second into two components that make with its direction angles of° and° respectively. Determine and record the magnitude of each component.

38.

Resolve a velocity of m. per second into components of magnitudes respectively of m. and m. per second. Determine the angle that each component makes with the given velocity.

39.

App.: English rule.

A ball is thrown horizontally with a velocity of 30 ft. per second. Disregarding the resistance of the air and taking $g = 32.16$ ft., locate by points 1, 2, 3, etc., the position of the ball at the end of half-seconds for three seconds. Draw a curved line through these points to represent the path of the projectile. Use scale 1:200.

¹ The numerics on this page are to be dictated by the teacher.



40 [Ex. XIV].

App.: 3 spring balances, 3 strings (each about 60^{cm} long) with loops at both ends, a square board of 1 ft. edge laid off into squares of 2 in. each with holes bored at each of the angles of the squares to receive iron pegs, 3 marbles or steel bullets.

(a) [For three pupils.]

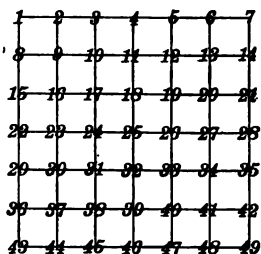


FIG. 19.

Insert three pegs in three holes in any one line (e.g. at 23, 25, and 27, Fig. 19). Place the board on the marbles spread apart. Let the pupils pull separately the several pegs by means of the strings and balances, keeping the strings horizontal and at right angles to the line joining the pegs. Produce equilibrium, and at a given signal let each read his balance. Make three trials, changing the position of the pegs each time.

Record as follows, using your own figures:

DATA.

CASE A.			CASE B.			CASE C.		
HOLE.	FORCE.	DIRECTION.	HOLE.	FORCE.	DIRECTION.	HOLE.	FORCE.	DIRECTION.
27	22	S	22	14	S	15	8.5	N
25	44	N	26	44	N	20	55.5	S
23	22	S	28	30	S	21	47	N

(b) State how the sum of the northerly forces compares with the sum of the southerly forces in the three cases.

(c) Choose in each case some point in the line joining the pegs (for example, 20 in Case C) for a center of moments or axis of motion, and compute the moment of each force and obtain the sum of the moments. Arrange work in each case in the following manner:

RESULTS.

Case C, center of moments at 20.

$$\begin{aligned}
 8.5 \times 5 &= +42.5 \\
 55.5 \times 0 &= 0 \\
 47 \times 1 &= -47 \\
 \hline
 \text{Sum} &= -4.5
 \end{aligned}$$

(d) State in general the relations between the forces and the distances of their respective points of application from the center of moments.

41 [Ex. XV].

App.: same as in Exp. 40.

(a) Returning to one of the cases of equilibrium (Exp. 40) let all the forces retain their original directions and magnitudes, and two of them their original points of application. Find, if practicable, a new point of application for the third force which shall leave the system in equilibrium as before. Take each of the other two forces in turn as the roving one, thus making three cases (*A*, *B*, and *C*), and record the several trials as in (a), Exp. 40.

(b) State your conclusion as to whether it is necessary that all the forces should have their points of application in the same straight line in order to produce equilibrium.

(c) Returning again to the three cases (Exp. 40), see if equilibrium may continue when the three forces have the same magnitude and points of application and, still remaining parallel to one another, are veered about into new directions. An easy way to accomplish this is to veer the strings about so that they will lie diagonally across the squares. Record the trials as in (a), Exp. 40.

42 [Ex. XVI].

App.: same as in Exps. 40 and 41, but with one more balance.

(a) [*For four pupils.*] Make three cases (*A*, *B*, and *C*) of equilibrium, using four balances pulling in four different directions (*e.g.* N, E, S, and W), but in every case applying the forces along the lines marked on the board. Record as in previous experiment.

(b) State any relation you may discover between the magnitudes of the forces N and S; between the forces E and W; between the forces N and E.

(c) Calculate in one of the cases of equilibrium the moments of all the forces with respect to some one of the pegs used considered as a center of moments, and compare the sum of the positive with the sum of the negative moments. Do the same with reference to another peg.

(d) From your experience state the condition necessary to an equilibrium of moments.



43 [Ex. XVII].

App.: plank about 1.5^m long with block attached at one end, a V-shaped horse (Fig. 24); a weight dish for suspension, a kilogram and a 2-kilogram weight, a meter stick, trip balance, and set of metric weights.

- (a) Weigh the plank which is to be regarded as a lever. Place it upon the horse and suspend the dish containing a kilogram weight at the end *A* (Fig. 20) of the lever. Bring the lever as near as possible to a balance upon the horse. Obtain and record data as follows :

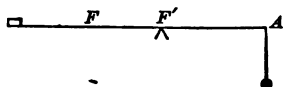


FIG. 20.

DATA.

Case A. Wt. of lever = ... kg. Wt. (including wt. of dish) applied at *A* = ... kg. Lever in equilibrium with fulcrum at *F'* (Fig. 20), $AF' = \dots\dots$ m.

- (b) Substitute the 2-kilogram weight for the kilogram weight and again bring the lever into equilibrium. Make measurements and record as follows :

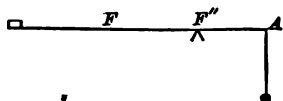


FIG. 21.

Case B. Wt. applied at *A* = ... kg. Lever in equilibrium with fulcrum at *F''* (Fig. 21), $AF'' = \dots\dots$ m.

- (c) Remove the suspended dish and bring the lever to a balance on the horse. Make measurements and record as follows :

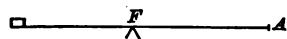


FIG. 22.

Case C. Lever in equilibrium with fulcrum at *F* (Fig. 22), $AF = \dots\dots$ m.

RESULTS.

(d) Case A. Consider the weight applied at *A* as one downward force and compute the distance from *F'* (i.e. $FF' = \dots\dots$ m.[?]) that the weight of the lever, if concentrated at one point (see ¶ 72, author's "Introduction to Physical Science"), would have to act to produce equilibrium with the force applied at *A*.

(e) Case B. Treat this case like Case A.

(f) How does AF ($AF' + F'F$), Case A, compare with AF , Case C? How does AF , Case B, compare with AF , Case C? Has the weight of the lever in the three cases acted as if applied at the center of mass of the lever?



44 [Ex. XII].

App.: 3 spring balances (30 lb.), 2 strong flexible strings about 75^{cm} long having loops at both ends, a metric rule, and a block of wood with straight edge.

(a) [*For four pupils.*] Tack a half-sheet of foolscap smoothly upon a table. Place the hooks of two of the balances in the loops of one of the strings. Slip one of the loops of the other string over this string, and in the free loop place the hook of the other balance. Place the junction of the strings centrally over the paper and let three pupils pull the three dynamometers horizontally, but in directions that are angular to one another. When equilibrium is produced (*i.e.* when the common point of application of the three forces, or the junction of the strings, is at rest) let the fourth pupil place the block consecutively against each of the three branches of the string and trace upon the paper three short lines to represent the directions in which the three forces act. *At the same time* let each of the three pupils read on his dynamometer the force with which he pulls.

Produce these lines to meet at a common point *A*. Lay off from point *A* on each of these lines distances to represent on a suitable scale¹ the magnitudes of the respective forces. Choose one of these forces to be regarded as an equilibrant of the other two, and letter the line *AB*. Draw also from *A* a line *AB'* of the same length as *AB*, but in the opposite direction, to represent the resultant of the same forces. Complete a parallelogram on the lines representing the component forces and draw a diagonal from point *A*.

(b) Does this diagonal correspond (approximately) to the line *AB'* which represents the resultant of the two forces?

¹ The parallelogram should be drawn to such a scale that it may be transferred from the paper to a blank page in the Manual. The transfer may be easily done by pricking with a pin through the paper the locations of the angles and then connecting these points by lines.



45.

App.: circular board loaded at some point as *e* Fig. 23, spindle *B*, plumb line, inclined plane, and measuring stick.

(a) Suspend the plumb line from the spindle and thrust the spindle through the hole *a* of the board *A*, and ascertain the line of direction of the board when supported at this point. Find, in the same manner, the line of direction when supported at *b*, and thereby determine the center of mass¹ of the board.

Thrust the spindle through each of the holes *a*, *b*, *c*, and *d*, and cause the board to rotate about each as a center. (1) About which

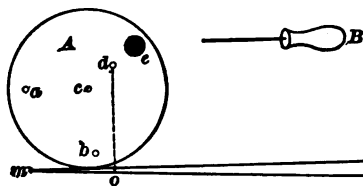


FIG. 23.

does the board rotate easily and freely, for the longest time, and with the least drag on the axle? (2) Where is the center of magnitude of this body?

(3) Where is its center of mass? (4) Where is its natural center of motion? (5) Which two of these three centers always coincide? (6) When will the center of motion coincide with the center of magnitude?

(b) Place the board *A* on a board *mn*, a little inclined and in a position as nearly as practicable like that shown in Fig. 23. (1) Remove your hand from the board *A*; it rolls along the inclined plane: why? (2) The board rolled up the inclined plane; did the body ascend or descend, *i.e.* did its center of mass ascend or descend? To determine this, place the body again in the original position, and close to the nearest edge of the inclined plane, measure the height of the center of mass of *A* above the desk (*i.e.* *do*); then let it roll and measure the height of the center of mass again and determine just how much the body (*i.e.* its center of mass) ascends or descends in rolling along the inclined plane.

¹ The center of mass (commonly called the center of gravity) of a body is a point where, for practical purposes, the entire mass of the body may be supposed to be concentrated (see Gage's "Principles of Physics," p. 53).



46 [Ex. XXI].

App.: 2 planks and 2 horses (Fig. 24), spring balance, small carriage and weights (5 to 10 lb.) with which to load the carriage, and yardstick.

(a) *Work and the inclined plane.* [For two pupils.] Place one end of one of the planks on the horse so as to make an inclined plane. Load the carriage with weights, place it on the inclined plane, and with string and balance pull it up the plane, keeping the string parallel to the plane. Determine the force necessary to keep the carriage moving with uniform velocity. Make several

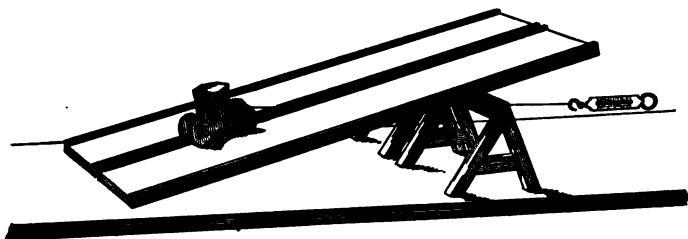


FIG. 24.

trials and find the average force. To determine the *effective force* used in raising the carriage, the friction must be eliminated as follows: allow the carriage to move down the plane with uniform velocity and find the pull on the balance parallel to the plane. Get the average of several trials. The mean of the two pulls (when the carriage is moving upwards and when it is moving downwards) is the effective force. Record as follows:

DATA.

Case A. Force parallel with plane, carriage moving up with uniform velocity = ... lb.

Ditto, carriage moving down = ... lb.

Effective force = $\frac{\text{. . . .} + \text{. . . .}}{2} = \text{. . . . lb.}$

Distance the force acts to raise the load to a vertical height of 2 ft. = ... ft.

(b) Place two planks on two horses side by side and at the same elevation, but separated about half an inch. Load the carriage as before and place it astride the space between the two planks.



Repeat all of (a), but pull *horizontally* by a string passed between the planks and horses, as in Fig. 24. Record as follows :

Case B. Force acting horizontally, carriage in uniform motion up = ... lb.
Ditto, carriage in uniform motion down = ... lb.

Effective force = $\frac{\dots + \dots}{2} = \dots \text{ lb.}$

Distance the force acts to raise the load to a vertical height of 2 ft. = ... ft.

(c) Suspend the carriage and load on balance and weigh.

Case C. Force acts vertically up. Weight of carriage and load = ... lb.
 Distance the load is raised = 2 ft.

RESULTS.

(d) Case A. Work = $FS = \dots \times \dots = \dots \text{ ft. lb.}$

" B. " = $FS = \dots \times \dots = \dots$ "

" C. " = $RS = \dots \times \dots = \dots$ "

(e) Compare the work done in the three cases of raising the load a vertical height of 2 ft.

(f) (1) In which case is there no gain of force ? (2) In which case is there the greater gain of force ?

47 [Ex. XIII].

App.: smooth pine plank and horse (Fig. 24), rectangular block about $8 \times 6 \times 4$ cm, 2 iron weights 8 oz. and 16 oz., meter stick, and spring balance graduated in half-ounces.

(a) *To find coefficient of friction.* [For two pupils.] Weigh the block in ounces. Lay the plank horizontal and on it place the block on one of its narrowest sides with its grain parallel to that of the plank. Tie a thread around the block and let one pupil pull on this thread with the balance parallel with the plane with such force as is necessary to keep the block moving with uniform velocity; the other pupil reads the balance when uniform motion is established. Record as follows :

DATA.

Case A. Load oz. Friction of block on narrow side oz.

(b) Place the block on its broad side, proceed as in (a), and obtain and record data for Case B.

(c) Load the block still on its broad side with 8-oz. weight and obtain data as hitherto for Case C.



(d) Substitute the 16-oz. weight for the 8-oz. weight and get data for Case D.

(e) Raise one end of the plank until the unloaded block still on its broad side once started will slide with uniform velocity. Then, placing the horse beneath the plank, measure the vertical distance from the under side of the raised end to the table and the horizontal distance from the foot of this vertical to the point where the

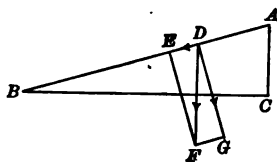


FIG. 25.

lower end of the plank rests upon the table. Record as follows :

Case E.

$$AB = \dots \text{ m.}$$

$$AC = \dots \text{ "}$$

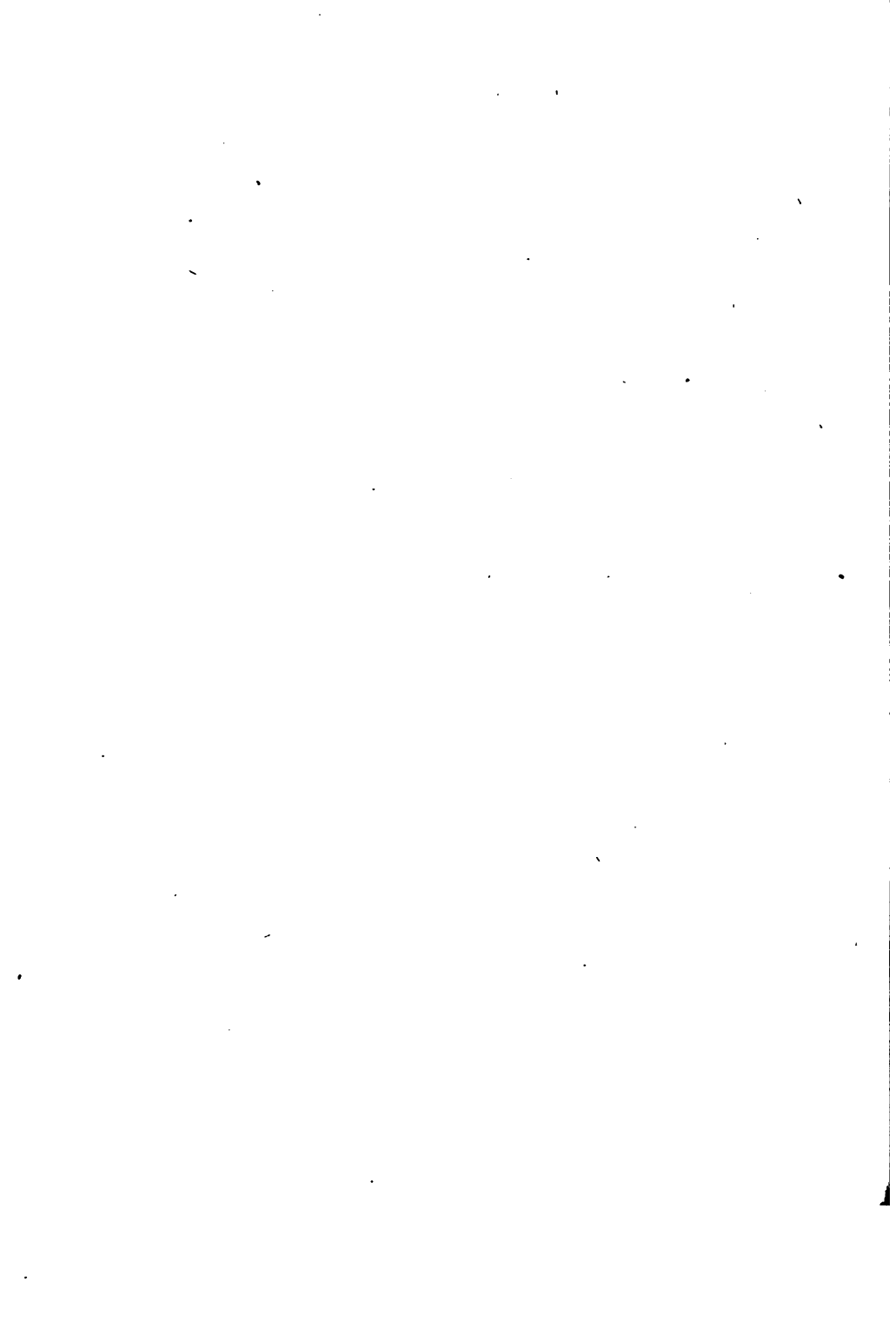
$$BC = \dots \text{ "}$$

$$DF = \dots \text{ oz.}$$

RESULTS.

(f) Case A.	$\frac{\text{Friction}}{\text{Pressure (i.e. load)}} = \frac{\dots}{\dots} = \dots$	coefficient of friction.
" B.	$\frac{\dots}{\dots} = \dots$	" "
" C.	$\frac{\dots}{\dots} = \dots$	" "
" D.	$\frac{\dots}{\dots} = \dots$	" "
" E.	$\frac{AC}{BC} = \frac{DE}{EF} = \frac{\dots}{\dots} = \dots$	" "

(g) (1) What triangles (Fig. 25) are similar to the triangle ABC ? (2) What force does the line DF represent? (3) What force does the line DG of EF represent? (4) Which line represents the force that balances friction? (5) In Case E, is the coefficient of friction the ratio of friction to pressure?



48 [Ex. XIX].

App.: 2 iron balls (about 1 in. diameter), each pierced by a small hole through the center, each suspended by a small tow-string or flexible wire, one measuring 100^{cm} from point of suspension to center of the ball, the other measuring 25^{cm} between the same points; a meter stick.

(a) Cause the ball of the long pendulum to vibrate for one minute each through arcs (about) 10^{cm}, 20^{cm}, and 30^{cm} long respectively, and record your results as follows :

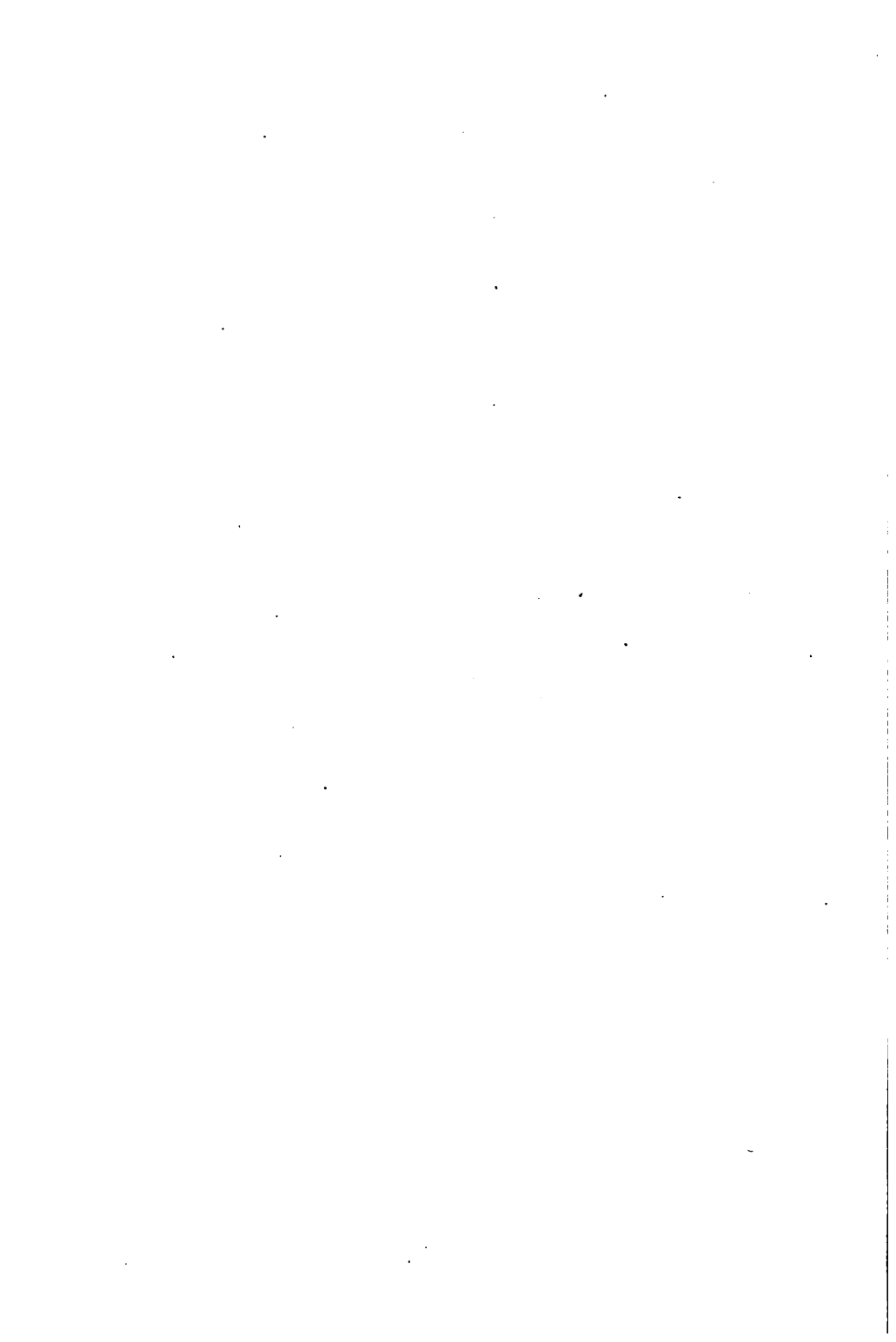
LENGTH OF ARC.	NO. VIBRATIONS PER MINUTE.
About 10 ^{cm}	
“ 20 ^{cm}	
“ 30 ^{cm}	

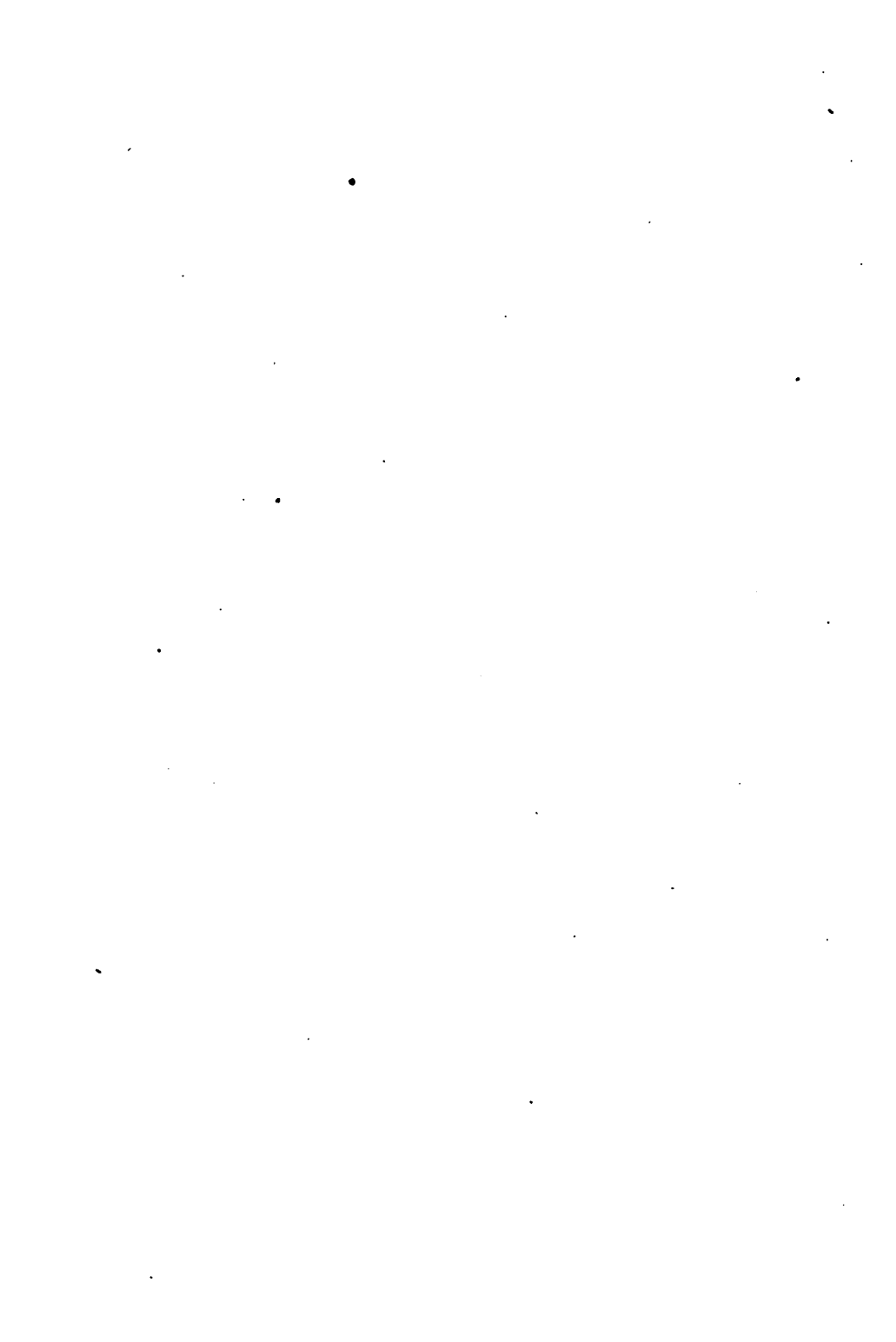
(b) Form a conclusion as to whether the number of vibrations made by a pendulum in a given time is independent of the length of the arc *provided the arc is never very great.*

(c) Find the length of each pendulum, measuring from the point of suspension to the center of the ball. Obtain and record data as follows :

LENGTH (l) OF PENDULUM.	NO. (n) OF VIB. IN ONE MINUTE.	TIME (t) OF ONE VIB.	$\sqrt{l}$.	$t \frac{1}{\sqrt{l}}$.
.....				
.....				
.....				

(d) Deduce a law of vibration of a pendulum, supplying the following ellipsis: *The time of vibration of a pendulum varies the length of the pendulum.*







52.

App.: board on which are fastened wires of (1) iron, (2) copper, (3) brass, and (4) German silver (Fig. 26); test-tube, and Bunsen burner.

(a) Support the board in a horizontal position, and place a lamp flame where the wires meet, so that all the wires will have an equal opportunity to get heated. Place fingers on both the iron and copper wires, near the flame, retreating as the heat becomes unbearable. You will find in time that the points which you touch reach a stationary stage, *i.e.* these points lose heat as fast as they receive it.

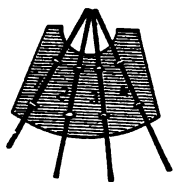


FIG. 26.

Observe the relative distances of the bearable points of the several wires from their heated ends, and arrange the metals in the order of their conductivity, beginning with the best conductor.

(b) In what ways do points along the wires lose heat, so that they ultimately reach a stationary temperature?

(c) Fill test-tube (Fig. 27) about four-fifths full of water, wipe



FIG. 27.

dry the outside, grasp it with the fingers near the bottom, and, inclining it a little, hold it in the flame of the burner, but do not allow the flame to lap over the empty portion of the tube. Continue heating until the water boils, and note (1) whether the water near the bottom gets hot. (2) Is it practicable to make a body of water hot by applying heat at the top? Why?

(3) Does this experiment show that water is a good or a poor conductor of heat?



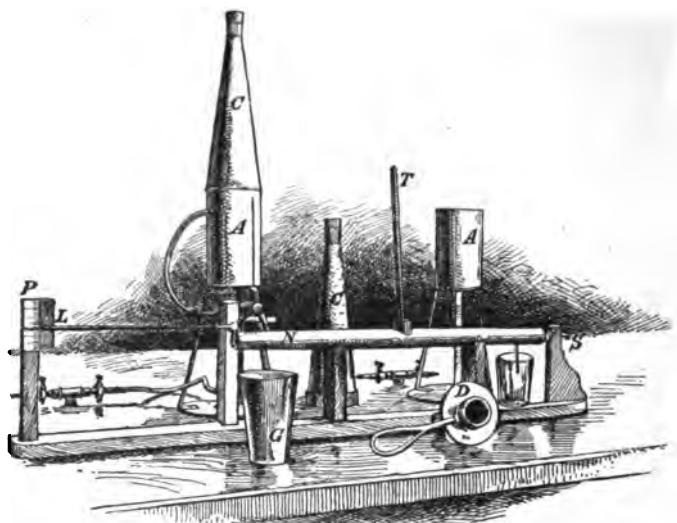


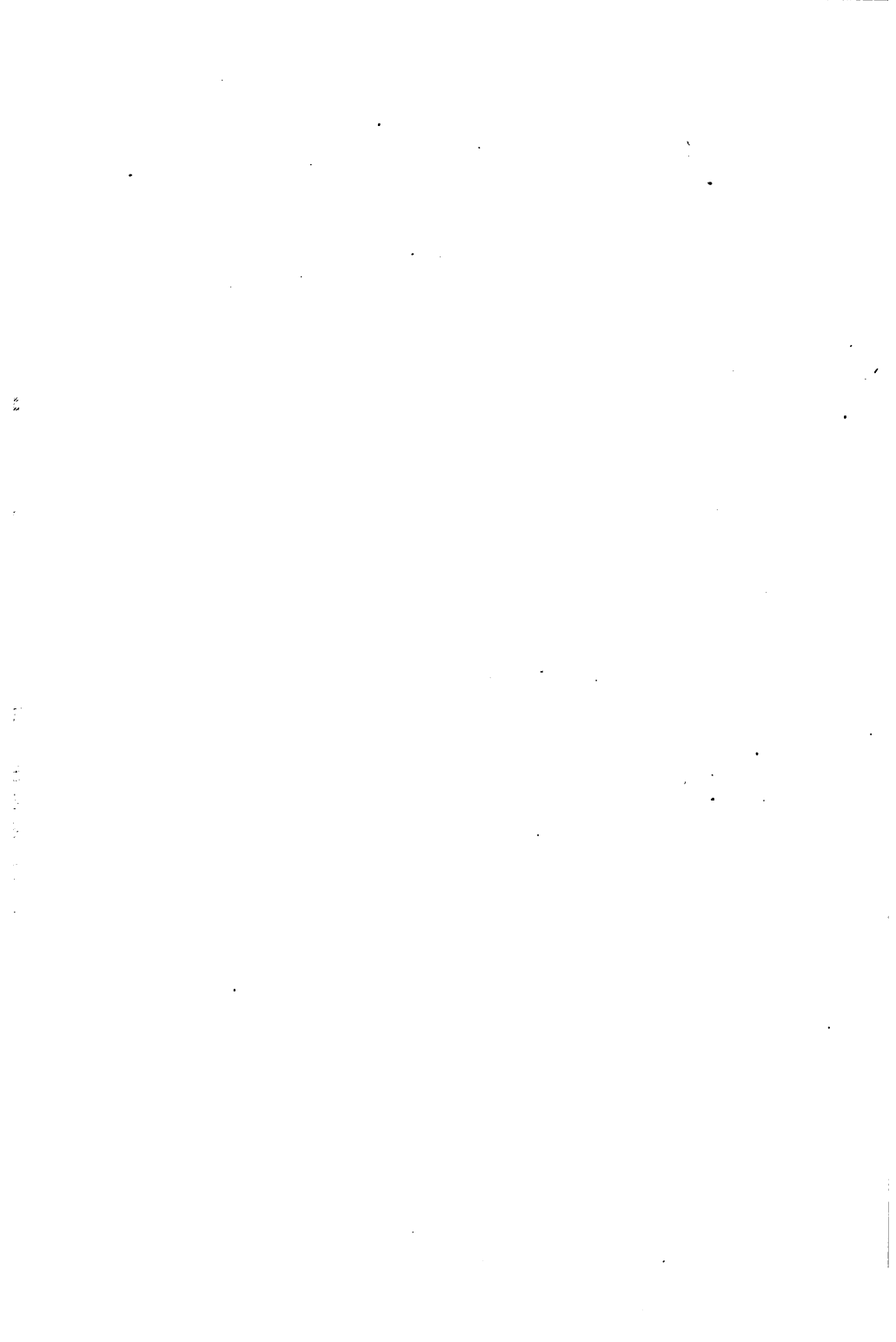
FIG. 28. — Collection of Heat Apparatus.

53 [Ex. XXIII].

App.: *A*, *C*, and *D* (Fig. 28); the thermometer to be tested, a quantity of snow or ice, and a barometer.

(a) *Testing a thermometer.* Fill the dipper *D* compactly with snow or *very fine* ice chips and add enough ice water to fill the intervening spaces. Thrust the bulb of the thermometer into the cup, leaving the freezing point not more than 1^{mm} above the liquid surface. Note the lowest point that the mercury reaches, and, assuming this to be the freezing point, determine the apparent error, if any, in the scale, stating whether the freezing point is too high or too low on the same. [Avoid handling the dipper except by the handle, and in reading place the eye on an exact level with the mercury surface. Read to the tenth of a millimeter.]

(b) Fill *A* with water to a depth of about 4^{cm} , put on *C*, close the side tube of *A*, thrust the bulb and stem of the thermometer down through the perforated cork in *C*, leaving the boiling point about 1^{mm} above the cork. [The bulb of the thermometer should not be nearer than 4^{cm} to the water.] Boil the water, and when the mercury has risen to its greatest height record the reading.



[When the water reaches the boiling stage it is best to check the flame a little so that the water may not boil so violently as to cause undue pressure of the partially confined steam.]

Read the barometer, and deduct from or add to the observed reading of the thermometer at the rate of 1° C. for 27^{mm} excess or deficiency in the height of the barometer column, 760^{mm} being considered the standard height. From the data obtained, calculate how much too high or too low, if any, the boiling point is marked on the scale.

(c) Allow the thermometer to cool in the air to 40° or 50° and repeat (a). State how much higher or lower, if any, the freezing point found at this trial is than that found in (a). This second or "lag" ice reading will probably be lower than the first, owing to the fact that the glass of the bulb does not change (*i.e.* contract) so rapidly as the mercury. It is usually taken as the zero of the scale.

54 [Ex. XXIV].

App.: Bunsen burner, app. A, C, and N (Fig. 28), and meter stick.

(a) *To find linear expansion coefficient of a substance, e.g. to find by what part of its original length a rod of brass increases when its temperature is raised 1° .* Press one end of the brass rod (which is surrounded by the steam-jacket N) against the screw S. The steel point at the other end of the rod should press against the short arm of the bent lever L, the whole being adjustable by means of the screw S. To prevent the jacket from rotating, cause the side tube (having the long rubber tube attached) to rest against a peg in the post that supports the lever.

Measure the long arm of the lever with great accuracy, *i.e.* from the axis of the lever to the nearest edge of the scale P; also measure the short arm of the lever, *i.e.* from the axis to the point of this arm where the steel point touches it. Take the reading of the lever on the scale P and the temperature of the thermometer T. Heat the boiler (which should be about one-third full of water) until the thermometer column heated by the steam flowing through the jacket becomes stationary. Then read the thermometer again and also the lever pointing on the scale P. While the water is heating, the pupil will measure the length of the brass rod by placing the meter stick against the steam-jacket. This measurement



should be made as accurately as circumstances will admit, but its accuracy is of rather small importance in comparison with that of other measurements. Record as follows :

DATA.

Length of long arm of lever	.....	cm.
" " short " " "	.....	"
First reading of scale	.....	"
Second " " "	.....	"
First " " temperature	.....	°
Second " " "	.....	°
Length of brass rod	.....	cm.

RESULTS.

(b) Determine (1) the distance the pointer moves on the scale ; (2) how many times the movement of the pointer multiplies the elongation ; (3) the actual elongation of the rod ; (4) the number of degrees of temperature the rod was raised ; (5) the amount of elongation per degree rise of temperature ; (6) the *coefficient of expansion*, i.e. what part of its original length the brass rod increased for an increase of temperature of 1°.



55 [Ex. XXVI].

App.: app. A, C, and N (Fig. 28), straight glass tube about 50^{cm} long, closed at one end and partly filled with dry air held in by a column of mercury and atmospheric pressure, a shallow basin having a tubulure or hole on one side through which the glass tube may be thrust, a small spirit level, a barometer, a quantity of ice or snow. [The glass tube partially filled with dry air may be procured of apparatus dealers, or it can be prepared by the teacher or an expert. It is of the utmost importance that the contained air be perfectly dry. Full directions for the preparation of these tubes can be found in Hall and Bergen's "Physica." In using app. N the lever is removed and the brass rod is removed from the steam-jacket N. A thread should be tied about this tube to serve as a marker. Should the mercury column in this tube become broken, it can be brought together easily by passing an iron wire through the bore.]

(a) *To find the coefficient of expansion of a body of dry air at constant pressure.* Thrust the air-filled portion of the tube through the hole in the side of the basin and pack about it chipped ice. Support the tube in an exact horizontal position (as determined by the spirit level), so that the pressure exerted upon the imprisoned air shall be the exact atmospheric pressure at the time. [If, however, the atmospheric pressure, as shown by the barometer, should change during the operation, the tube must be tilted so as to compensate for the change in atmospheric pressure, in order that the pressure on the contained air may remain perfectly constant.]

When the air column has attained its minimum volume for the temperature which is assumed to be 0° C., slip the thread along the tube so as to mark exactly the inner end of the mercury column, which should be as near the ice as practicable, in order that the whole air column may be cooled. Measure the distance from the closed end of the bore to this thread. This distance represents the volume of the enclosed air at 0° C.

(b) Remove the tube from the ice and introduce the air-filled portion into the end of the steam-jacket and adjust its level as before so as to adapt the pressure to the atmospheric pressure. Boil the water in the boiler and envelop the tube with steam which fills the steam-jacket. When the volume of air ceases to increase, slip the thread along the tube so as to mark exactly the inner end of the mercury column, which should be as near the steam as possible. Remove the tube and measure the distance from the end of the bore to the string. This distance represents the volume of the body of air at the temperature of the steam.



(c) Calculate the temperature of the steam arising from water boiling under an atmospheric pressure as indicated by the barometer (see Exp. 53). Record results as follows :

DATA.

Barometer reading cm.
 Computed temperature of air when enveloped by steam°
 Total rise of temperature°
 Length of air column at 0° cm.
 " " " " "° cm.

RESULTS.

(d) Find (1) the total increase of volume of air in rising from 0° to the temperature of the steam; (2) what part this total increase is of the volume at 0°; and (3) by what part of its volume at 0° the air expands for a rise in temperature of 1°. [Express the results of all these computations decimally.]

(e) At the rate as determined in (d), at what temperature would 1^{cc} of dry air, measured at 0° and kept under a constant pressure, become 2^{cc}?

56 [Ex. XXV].

App.: same as in Exp. 55 except that the glass tube containing columns of mercury and air is about 1^m long and is bended at its middle at a right angle.

(a) *To find the coefficient of air pressure at constant volume, i.e. the ratio which the increase of pressure per 1° C. throughout a certain range of temperature bears to the pressure at 0°.* Bury the air-filled portion of the tube in ice, as in (a), Exp. 55, so adjusting the tube with the spirit level that the entire mercury column shall lie in a horizontal plane. In this position the pressure of the imprisoned air is just equal to the atmospheric pressure at the time. As soon as the volume of air reaches its minimum for this temperature (which is assumed to be 0°), slip the thread along the tube so as to mark exactly the inner surface of the mercury column.

Transfer the tube to the steam-jacket as in (b), Exp. 55, boil the water and invest the air-filled portion of the tube with steam. The pupil is to bear in mind that in this experiment *the volume of the air is to be kept constant*. So, as the pressure of the air increases with rise of temperature, he must tilt the open arm of the tube upward, thereby adding constantly to the atmospheric pressure a

pressure dependent upon the vertical height of the outer mercury surface above the inner surface, and such as to keep the latter surface constantly at the thread marker.

(b) When the pressure of the air reaches its maximum, measure from a horizontal plane below (*e.g.* from a spirit level) vertically to both the inner and outer surfaces of the mercury in the tube. The difference between these two measurements represents the increase in pressure of the air due to a change in temperature from 0° to the temperature of the steam.

(c) Calculate the temperature of the steam arising from water boiling under an atmospheric pressure as indicated by the barometer. Record results as follows :

DATA.

Barometer reading cm.

Computed temperature of air when enveloped by steam $^{\circ}$

Total rise of temperature $^{\circ}$

Pressure of air at 0° (taken from barometer) cm.

Height of outer surface of mercury above horizontal plane when pressure of air is at its maximum cm.

Height at the same time of the inner surface cm.

Total increase of pressure due to rise of temperature from 0° to the temperature of the steam cm.

RESULTS.

(d) Find (1) what part the total increase of pressure (due to the rise of temperature from 0° to the temperature of the steam) is of the pressure at 0° (as indicated by the barometer); (2) by what part of its pressure at 0° its pressure is increased for a rise of temperature of 1° (*i.e.* the coefficient of air pressure at constant volume through the range of temperature used). [Express these results decimally.]

(e) At what temperature would the pressure of air be double that at 0° C. if kept at a constant volume ?

(f) Assuming that the pressure of air diminishes with reduction of temperature by the same constant coefficient (as found), how many degrees below 0° C. must a body of dry air be reduced that its pressure may become zero, *i.e.* viewed theoretically, how many degrees below 0° C. is the *absolute zero* according to your calculations ?



57.

App.: same glass tube as used in Exp. 56, barometer, spirit level, and meter stick.

(a) [There are obvious advantages to be derived in many cases from substituting this experiment for Exp. 20 and performing this in connection with the two preceding experiments.] The pupil is cautioned that in this experiment *the temperature of the imprisoned air must be kept constant*. Consequently, he must handle the tube only near its open end, so as not to communicate heat from the hand to any part containing mercury or enclosed air. Lay the tube horizontally upon the table and test its horizontality with the spirit level. Measure from the closed end of the tube to the inner surface of the mercury. This distance represents the volume of the enclosed air under the existing atmospheric pressure as indicated by the barometer.

Raise the open end of the tube a few (say 10 to 15) centimeters and rest it upon some steady support. Measure again the volume of the enclosed air. Also ascertain the vertical height of the outer surface of the mercury above the inner surface. This height plus the height of the barometer column represents the present pressure. Continue to elevate the open end (10 to 15^{cm} at a time) for at least four times, and ascertain each time as before the corresponding volume of air and pressure. Record as follows :

DATA.			
Volume		Pressure	
(in cm.)		(in cm.)	
1	.....	×	..... = .....
2	.....	×	..... = .....
etc.	etc.	etc.	etc.

(b) What relation between the volume and the pressure of a body of gas kept at a constant temperature do your results indicate ?



58 [Ex. XXII].

App.: as shown in Fig. 29, except that a (250^{cc}) flask is more convenient; app. for heating. Both flask and tumbler contain cold water.

(a) Heat the water in the flask and after it has boiled about five minutes remove the heat, but leave all other apparatus as before.

Observe carefully and explain every phenomenon that occurs from the time when you first apply heat till the expiration of ten minutes following the withdrawal of heat. Be especially careful in observing any bubbling, and state when, where, and why the bubbles occur, whether they rise to the surface, where they burst, whether they are bubbles of air or steam, and the reason for your statement, whether during the operation the bubbles change in character, whether there is any change in the size of the bubbles as they rise, and if so why; whether there is any "singing" noise

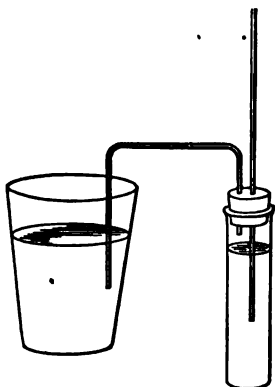


FIG. 29.

produced at any time, and if so where and how; whether during the operation water is transferred from either vessel to the other, and the cause. *Arrange statements concerning the phenomena observed in the order of their occurrence.*

59 [Ex. XXII].

App.: thermometer, calorimeter *G* (Fig. 28), glass beaker, hygrometer, and a quantity of ice or snow.

(a) *Find the dew-point of the air in the room.* [Caution: Handle the calorimeter as little as possible and only near its upper edge, and throughout your observations direct your breath away from the calorimeter as much as possible, so that the moisture of your breath may not change the condition of the air in the vicinity of the calorimeter.] Pour water at a temperature about 5° below that of the room into the calorimeter until it is about half full. Place the bulb of the thermometer in the water, and do not remove it from the water throughout the experiment. Very gradually reduce the temperature of the water in the calorimeter by stirring into it ice water from the beaker till you discover a slight dimness on the portion of the outside next the water. Pour some of the water out from the calorimeter from time to time, so as to enable you to reduce the temperature of its contents lower. It may be necessary to reduce the temperature of the ice water below 0° by surrounding the beaker with an ice and salt mixture [use what grocers call "coarse fine" salt].

Note the temperature of the water when the dimness first appears, also when it disappears. Take the mean of the two temperatures for the dew-point. Record as follows:

Temperature at which dew appears
 " " " " disappears
 Average temperature
 Humidity of air in laboratory as indicated by
 the hygrometer (expressed as a %)

(b) Is it probable that the dew-point of the air out of doors at the time this experiment is performed is higher or lower than that indoors? Why?

60 [Ex. XXVII].

App.: app. *A*, dipper *D*, calorimeter *G* (Fig. 28), 2 thermometers, trip-balance, and weights, about 400^s of bird shot.

(a) *To find the specific heat of a solid.* Weigh in the dipper about 400^s of shot and put the dipper into app. *A*, which contains water reaching nearly to the bottom of the dipper. Bury the bulb of the thermometer in the shot and thrust the stem of the same through a piece of pasteboard which serves as a cover. Boil the water and occasionally stir the shot with the thermometer. Mean-time weigh the calorimeter and place in it about 100^s of water at about 7° to 10° below the temperature of the air. When the shot have acquired a nearly constant temperature, take their temperature and that of the water in the calorimeter, pour the shot into the calorimeter, stir with the thermometer with which the temperature of the water was taken, and take the temperature of the water as soon as the shot and the water have the same temperature. Record as follows:

DATA.

Mass of water $m = \dots \text{k.}$
 " " shot $m_1 = \dots \text{k.}$
 " " heated part of calorimeter $m_2 = \dots \text{k.}$
 Temperature of water $t = \dots^\circ \text{C.}$
 " " hot shot $t_1 = \dots^\circ \text{C.}$
 " " mixture $t_2 = \dots^\circ \text{C.}$
 Specific heat of brass (calorimeter) = .09
 " " " lead (shot) = x .

RESULTS.

(b) The expression for the heat lost by the shot is

$$(m_1 \times x) \times (t_1 - t_2).$$

The amount of heat gained by the heated part of the calorimeter is

$$(m_2 \times .09) \times (t_2 - t).$$

Make an expression for the heat gained by the water. Then, since the heat lost by the shot is equal to the heat gained by the calorimeter and water (on the assumption that no heat has been lost or gained by radiation, etc.), an equation may be formed from which the value of x may be obtained.

61.

App.: 3 test-tubes, 3 small beakers, 3 thermometers, balance and weights, a vessel for boiling water, and a Bunsen burner.

[*For three pupils.*] Weigh into the separate test-tubes 60^g each of shavings (or filings) of iron, copper, and lead. Suspend the test-tubes in the vessel of boiling water for 7 minutes. Mean-time weigh into each of the beakers 60^g of water at a temperature of 5° to 10° below that of the room. Ascertain the temperature of the water. Remove the test-tubes and quickly pour the contents (assumed to be at 100°) into separate beakers; stir with thermometers and note carefully the highest temperature which the water reaches in each beaker. Record as follows:

DATA.

Temperature of cold water	°
“ “ iron and water	°
“ “ copper “	°
“ “ lead “	°

RESULTS.

60 ^g of iron cooling	°	heat 60 ^g of water	°
“ “ copper “	°	“ “ “ “	°
“ “ lead “	°	“ “ “ “	°

∴ 60 ^g of iron in cooling 1°	heat 60 ^g of water	<u>.....°</u>
“ “ copper “	“ “ “ “	<u>.....°</u>
“ “ lead “	“ “ “ “	<u>.....°</u>

∴ specific heats of water, iron, copper, and lead are as

$$1 : \frac{.....}{.....} : \frac{.....}{.....} : \frac{.....}{.....}$$

or, expressed decimally, as

$$1 : : :$$



62 [Ex. XXVIII].

App.: calorimeter, thermometer, trip-balance, and weights.

(a) [*For two pupils.*] Find the quantity of heat rendered latent in melting 1^k of ice. Weigh the calorimeter. Put into it about .2^k of water having a temperature between 55° and 65°. Weigh the water. Estimate the portion of the calorimeter that is heated by the water. Put the thermometer into the water and keep it there until the experiment is completed. Quickly provide about three-fourths of a tumblerful of small dry chips of ice. Take the temperature of the water and immediately pour the ice into the water. Stir with the thermometer till all the ice is melted; then immediately take the temperature of the mixture. Weigh the water now in the calorimeter and determine the weight of ice that has been melted. [Caution: *After the ice has been poured into the water, do not handle the calorimeter so as to communicate heat to it from your hand.*]

DATA.

Wt. of calorimeter = ... k.

" " hot water (w) = ... k.

" " ice melted (w_1) = ... k.

" " heated part of calorimeter (w_2) = ... k.

Water equivalent of heated part of calorimeter = $w_2 \times .09$.

(The s.h. of brass of which the calorimeter is made is .09.)

Temperature of hot water (t) = ...°

" " mixture (t_1) = ...°

x = quantity of heat rendered latent in melting 1^k of ice.

RESULTS.

(b) From the above data make an equation (assuming that all the heat that the hot water and the heated part of the calorimeter lose goes toward melting the ice and raising the temperature of the resulting water to the temperature t_1°) and find the value of x . [First find an algebraic expression for the quantity of heat that the hot water (w) and the heated part of the calorimeter (w_2) surrender. Then find an expression for the quantity of heat required to raise the water resulting from melting the ice (w_1) from 0° to t_1° . The difference between these two quantities of heat is evidently the number of calories of heat rendered latent in melting the (w_1) ice. This known, the quantity of heat required to melt 1^k of ice may be computed.]



63 [Ex. XXIX].

App.: app. *A*, *C*, *D*, and *G* (Fig. 28), thermometer, Bunsen burner, trip-balance, and weights. The boiler *A* is filled one-third full of water, the apex of *C* is closed, and also the side tube near the apex. A short glass tube is connected by a rubber tube connector to the side tube of *A*. This glass tube is to dip a little way into water that is to be put into the calorimeter *G*. The calorimeter should be supported so that its top shall nearly reach the level of the side tube of *A*. A thin board perforated so as to allow the side tube to pass through it should be placed between the boiler *A* and the calorimeter, so as completely to protect the latter from heat radiated from the flame and the boiler.

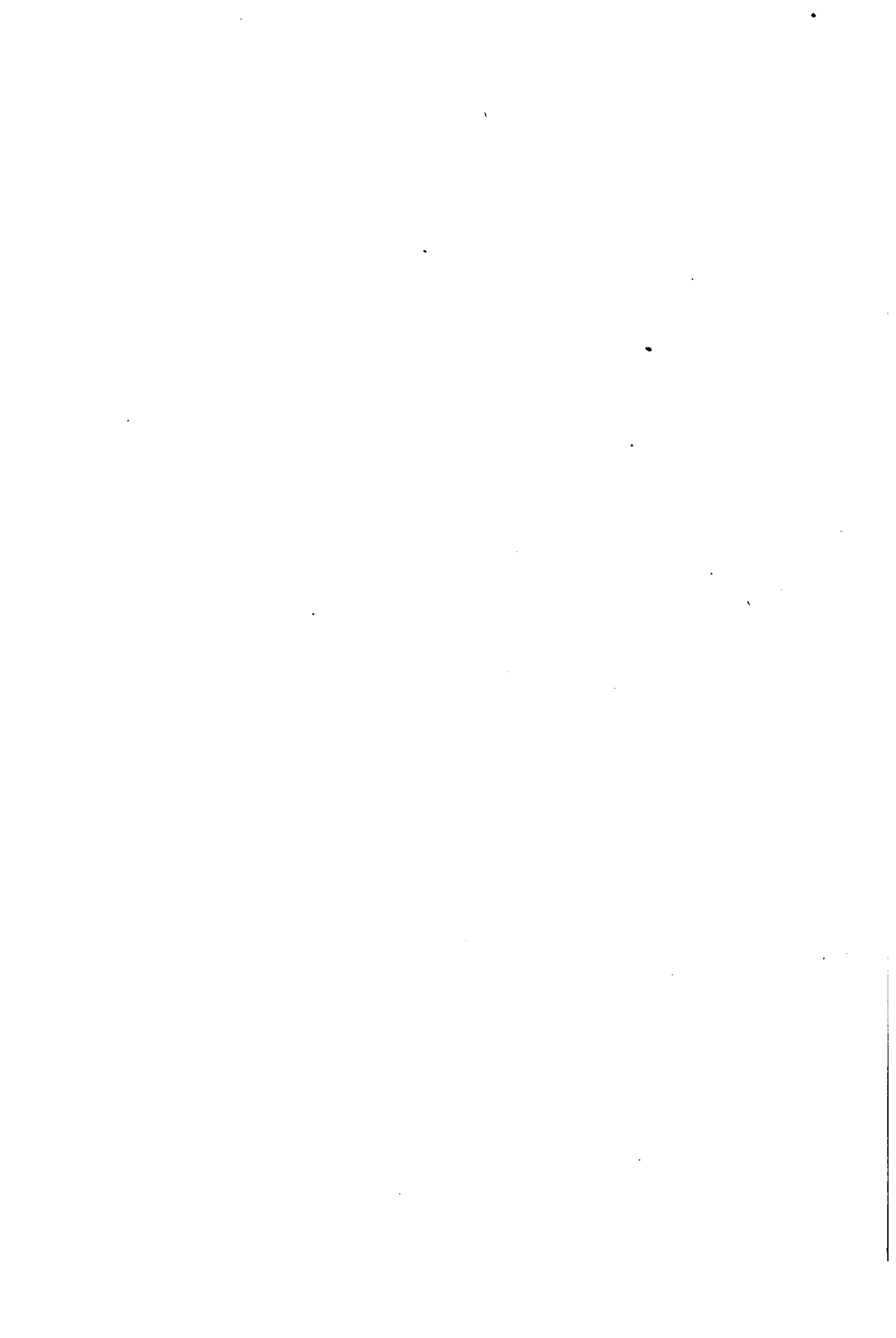
(a) *Latent heat of vaporization.* [For two pupils.] Heat the water in the boiler. Weigh the calorimeter and then weigh in the calorimeter 275^g of water whose temperature is about 15° below that of the room. After the water begins to boil, catch in a small beaker the drops of water (resulting from condensation of steam in the tube) that drip from the tube during 5 minutes. Take the temperature of the water in the calorimeter and quickly insert in it the steam-conducting tube. Cover the calorimeter with a pasteboard having two perforations through which pass the tube and thermometer. Note the time which elapses between the instants when the steam tube is put in and taken out of the water. Frequently stir the water with the thermometer. When the temperature has risen about 15° above the temperature of the room, remove the tube, stir the water with the thermometer and take its temperature with the least possible loss of time. Weigh the calorimeter and contents and find the increase in weight due to the condensation of steam. Find the weight of so many drops of water as fell during 5 minutes. Record results as follows:

DATA.

Wt. of calorimeter	k.
“ “ “ and cold water	k.
“ “ “ “ warm “	k.
“ “ drops that fell in 5 min.	k.
Length of time steam was condensed	minutes.
Temperature of cold water	°
“ “ warm “	°

RESULTS.

(b) Calculate the weight of water added to the contents of the calorimeter as a consequence of condensation *in the tube*, assuming



the condensation to continue at the rate ascertained during 5 minutes. Deduct this from the total increase of weight due to condensation, and thus ascertain the weight of steam condensed in the water.

(c) Let x denote the number of calories of heat generated in the condensation of 1^k of steam at 100° into water at 100° . Find how many calories are generated by the whole quantity of steam that was condensed in the water.

(d) Calculate how many calories of heat are communicated to the cold water by the whole quantity of water at 100° (including that condensed in the water and in the tube) in falling from 100° to the temperature of the mixture.

(e) Find the water equivalent of the estimated portion of the calorimeter heated, allowing its specific heat to be .09.

(f) Find how many calories are required to raise the whole weight of cold water and a portion of the calorimeter from its first temperature to the temperature of the mixture.

(g) Make an equation, taking for one member the quantity of heat generated by the condensation of steam in the water [as found in (c)] plus the quantity of heat communicated by the water in cooling to the temperature of the mixture [as found in (d)]; for the other member, take the quantity of heat required to raise the cold water and portion of calorimeter to the temperature of the mixture [as found in (f)]. Solve the equation and find (x) the number of calories of heat generated in the condensation of 1^k of steam at 100° into water at 100° .



64.

App.: perforated iron ball 3 to 4^{cm} in diameter, calorimeter, thermometer, balance, weights, vessel of water, and 2 Bunsen burners.

(a) *Find the temperature of the iron ball when raised apparently to the temperature of the flame, and thereby ascertain approximately the temperature of the flame.*

Weigh the calorimeter (w_1). Fill it two-thirds full of water and find the weight of the water (w_2). Weigh the ball (w_3). Suspend the ball by a small platinum wire and cover it with the flames of the two lamps and heat as hot as possible.

Take the temperature (T_1) of the water in the calorimeter (which should be about 12° below that of the room) and quickly plunge the hot ball into the water. Move it about until the water attains its maximum temperature as shown by a thermometer placed in the water. Note this temperature (T_2). Record results as follows :

DATA.

Weight of calorimeter (w_1) = ... k.

“ “ water (w_2) = ... k

“ “ ball (w_3) = ... k

Water-equivalent of calorimeter ($w_1 \times .09$) = ... k

Temperature of cold water (T_1) °

“ “ water heated by ball (T_2) °

RESULTS.

(b) Let x represent the temperature (sought) of the ball (or flame).

$$\text{Then } 0.11 \text{ (specific heat of iron)} = \frac{w_2 + (w_1 \times .09)}{w_3} \times \frac{T_2 - T_1}{x - T_2}.$$

Thence obtain the value of x .

(c) State probable sources of error.

56

HEAT.

65.



66 [Ex. XL].

App.: bar magnet 15 to 20^{cm} long, compass not exceeding 3^{cm} in diameter, sheet of white paper 60^{cm} square.

(a) Draw a straight line through the center of one of the large sheets of paper parallel to two of its edges. Place the compass on this line and rotate the paper so that the needle will point along the line, *i.e.* so that the line will lie in the magnetic meridian. Place one of the bar magnets on this line with its N-pole pointing to the magnetic north, and its S-pole one inch from the southern edge of the paper. Trace on the paper a line around the magnet and keep the magnet within this boundary line throughout the experiment.

Place the compass on the paper in contact with the northeast corner of the magnet and so that the center of the compass will be northeast from this corner. Indicate by a point on the paper close to the compass the direction in which the needle points. Move the compass and place its center over this point, place another point as before, and so continue until the needle reaches a point where it is parallel to the line drawn through the paper, *i.e.* has got beyond the influence of the magnet. Trace upon the paper from the northeast corner of the magnet a line through the several points.

Then place again the compass against the magnet with its center about 1^{cm} from the northeast corner toward the middle of the magnet, set points, and trace another line as before. Start another line 1^{cm} from the last and nearer the middle, and continue the line until it either gets beyond the influence of the magnet or returns to the magnet. So continue to trace lines from points each time 1^{cm} nearer the middle until a line is obtained that returns to the magnet.

Trace a line from the northwest corner of the magnet similarly situated to the first line drawn. Trace another line from a point on the west side of the magnet opposite the origin of the last line drawn on the east side.

(b) Place a compass on the last line drawn, carry its center along the line, and at intervals of about 4^{cm} place points, and at these points draw short straight lines (each terminating at one end with an arrow head) to show the direction in which the needle points at the several points.



(c) State (on your paper) what the position of the needle is at the several points, with reference to the line of magnetic force. Making use of this discovery, frame a provisional definition of a line of magnetic force.

(d) Measure in a straight line from the northeast corner of the magnet to a point in the first line drawn where the needle seems to have reached the limit of the magnet's influence, and state approximately the extent of the magnetic field in that direction.

67 [Ex. XL].

App.: same as in Exp. 66.

Place the magnet centrally on a sheet of paper with its N-pole pointing south. Trace, as in Exp. 66, lines from the northeast corner of the magnet and others from points 1^{cm}, 2^{cm}, 3^{cm}, and 4^{cm} toward the middle.

68 [Ex. XL].

App.: 2 bar magnets, sheet of paper 30^{cm} square.

(a) Lay 2 bar magnets centrally on the small paper parallel to each other and to two edges of the paper. The magnets should be placed about 12^{cm} apart with both N-poles pointing north. Trace, as previously, a line from the northeast corner of the western magnet, and others from points 1^{cm}, 2^{cm}, 3^{cm}, and 4^{cm} from this point. Trace lines from similar points on the western side of the eastern magnet.

(b) Trace a neutral line between the two magnets.

(c) State (on your paper) whether a magnetic needle is ever or anywhere free from the directive influence of the earth's magnetism. How, then, is the position of a magnetic needle at any point in the field of a magnet determined?

69 [Ex. XLI].

App.: tumbler containing dilute sulphuric acid (1 part of acid by volume to 20 parts of water), strip of sheet copper, and 2 strips of zinc (one amalgamated), each of the strips of metal 10^{cm} long, 2^{cm} wide, and the zinc strips 3 to 4^{mm} thick, each strip having a piece of wire (No. 16) 30^{cm} long soldered to one of its ends; double connector, and galvanoscope (Fig. 30).

(a) [For two pupils.] Put the copper strip into the liquid.

State what, if any, phenomenon occurs, especially whether there is any trace of chemical action observable.

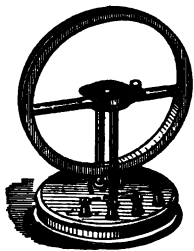


FIG. 30.

(b) Place the unamalgamated zinc in the liquid, but do not allow it to touch the copper strip. State what, if any, phenomena occur.

(c) Set the galvanoscope, i.e. so place it that the needle shall point to zero, and its axis, — a straight line joining its poles, — shall be parallel to the wires in the coil of the galvanoscope.

Introduce the free ends (electrodes) of the wires into the screw-cups at the terminals of the 15-turn coil of the galvanoscope. [While one pupil does this another pupil should hold the galvanoscope firmly upon the table, so that it may not be moved from its "set" position.] Keep the strips quiet and as widely separated from each other in the tumbler as possible. *Note what occurs at the surface of each strip.* As soon as the needle comes to rest, read and record in degrees the angle of deflection.

(d) Remove the zinc strip, wait until the liquid becomes clear, then introduce the amalgamated zinc. If there appears to be any chemical action, withdraw it from the cell and thrust it into a tumbler of mercury and, after wiping it with a cloth, again introduce it into the cell.

Connect the electrodes with the galvanoscope as in (c) and keep the strips in the same relative positions as before. Note what occurs at the surfaces of the two strips. Read and record the deflection of the needle. Then at intervals of 2 minutes for 12 minutes read and record the deflections.

(e) State your opinion as to the *constancy* of the current which the cell yields.

(f) A current-bearing wire is said to be capable of exerting an *electro-magnetic force*. What evidence of the existence of such a force have you seen?

(g) If the zinc be amalgamated, how can chemical action be stopped without removing either metal from the liquid?

70 [Ex. XLII].

App.: galvanoscope (Fig. 30), balance, set of weights, Bunsen burner, Daniell cell constructed as follows: A glass jar (about $10^{\text{cm}} \times 10^{\text{cm}}$) containing saturated solution of copper sulphate, a porous cup (about $10^{\text{cm}} \times 4.5^{\text{cm}}$) containing dilute sulphuric acid, and an amalgamated zinc plate ($10^{\text{cm}} \times 3^{\text{cm}} \times .4^{\text{cm}}$). Outside the porous cup is a piece of sheet copper ($10^{\text{cm}} \times 10^{\text{cm}}$) curved around the porous cup. Both elements have wires soldered to them.

(a) Weigh to the tenth of a gram both elements. Connect each electrode with the screw-cups at the terminals of the 5-turn coil of the galvanoscope. Set the galvanoscope, and then, without disturbing it, introduce the two elements into their proper places in the cell. Note the deflection at the beginning and at intervals of 5 minutes thereafter for half an hour.

(b) At the expiration of the half hour remove the elements, rinse them in water, and, being careful not to shake or rub off any of the adhering copper, dry them by holding them about 1 ft. above a burner. Weigh the dry elements again and note and record any changes of weight.

(c) State your opinion as to the constancy (or inconstancy) of this cell and the reason therefor.

(d) Calculate from the data obtained the average strength of current of the cell during the operation, copper being deposited by a uniform current of one ampere at the rate of .0003284^g per second.

71.

App.: Bunsen or Daniell cell and magnetic needle (Fig. 31).

[Before performing this experiment the pupil should be able to make a diagrammatic drawing of a cell and open circuit, applying the proper signs to each of the elements and to each of the electrodes. He should be instructed to confine his attention to the N-pole of the needle.]

(a) Place the apparatus (Fig. 31) so that the needle pointing north shall be parallel to the wires W_1 and W_2 , and so that the brass connector C shall face the north. Insert the positive electrode (+ E) of the cell into screw-cup T_2 , and the - E into T_1 .

Record: Current flows (N or S) (above or below) the needle. Needle is deflected (E or W).

(b) Place the palm of the outstretched right hand so that the current-bearing wire shall be between it and the needle and so that the fingers point in the direction the current flows.



Record: In the *right-hand test* the needle is deflected in a direction (the same as or opposite to) that of the thumb.

(c) Break the circuit.

Record: Under the magnetic influence of the earth the needle, etc. (here state what happens to the needle).

(d) Reverse the direction of the current through the same wire W_1 and apply the right-hand test again.

Record: Current flows (N or S) (above or below) the needle; the needle is deflected (E or W) and in a direction (the same as or opposite to) that of the thumb.

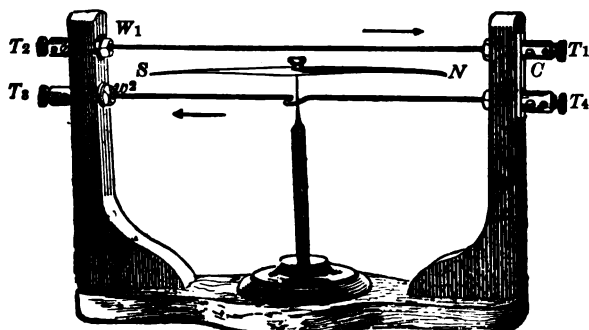


FIG. 31.

(e) Send the current in the same direction as in (d) through the lower wire W_2 , apply the test as before, and record as before. [Observe that in this case, in order to carry out the instructions given in (b), the hand must be placed *under* the wire.]

(f) Reverse the current in wire W_2 , apply test, and record as hitherto.

(g) Insert the $+E$ into T_2 and the $-E$ into T_3 . [See that the brass connection C between T_1 and T_4 faces the north.]

Record: Current above the needle flows (N or S), below the needle (N or S). By the *right-hand test* the current above the needle should cause a deflection to (E or W), and the current below the needle to (E or W); hence the deflection should be (greater or less) than in previous cases. This (corresponds or does not correspond) with my observation.

(h) Devise a rule for determining the direction of the deflection when the direction of the current is known.

(i) State the converse of this rule, i.e. give a rule for determining the direction of the current by observing the direction of the deflection produced by it.

(j) State in what two ways the direction of a deflection may be reversed.

72 [Ex. XLIII].

App.: Bunsen cell, 2.5^m of No. 20 wire, small compass.

[Bend the wire into a square and place it upon a table so that two of its sides will run east and west, introduce the cell at the southwest corner of the square in such a manner that the current will flow eastward through the southern side of the square, and tack the other three corners of the square to the table.¹]

- (a) Place the compass over the middle of the south side, and note the direction assumed by the needle. Then place the compass beneath the same point of the wire and note the direction taken by the needle.

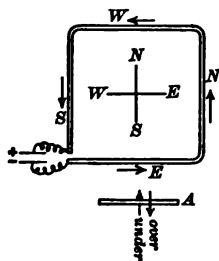


FIG. 32.

- (b) Continue the observations in (a) at the middle of each of the remaining sides of the square. Draw a diagram similar to Fig. 32 and represent the directions assumed by the needle at each point as shown in A.

(c) If the palm of the right hand be placed opposite the needle in any case with the wire between the palm and the needle, and the fingers pointing in the direction the current flows in that part of the circuit, is the deflection of the N-seeking pole of the needle in the same or opposite direction to that in which the outstretched thumb points?

(d) A line of magnetic force is said (arbitrarily) to have the direction in which the N-pole of the needle points when placed on the line. To a person looking along a wire in the direction the current flows, do the lines of force run around the wire in the same direction as that of the twisting motion of a corkscrew when propelled, or in the opposite direction?

¹ It is advisable to use a wire long enough that it may be carried two or three times around the square, the several turns being kept together and in place by staple tacks at the corners of the square.

73 [Ex. XLIII].

App.: Daniell cell, galvanoscope, and meter stick.

[Place the galvanoscope so that the plane of the coil will be east and west, and so connect the cell with the 15-turn coil that the current will flow from E to W on the top of the coil. Thrust the meter stick horizontally through the coil, allowing it to rest upon the compass-support at its center. The stick should lie in the magnetic meridian of the earth and be at right angles to the plane of the coil.]

(a) Place the compass on this stick 10^{cm} south of the center of the coil. Note the direction taken by the needle. Move the compass northward on the stick in four stages of 5^{cm} each, recording the direction of the needle at each stopping place.

(b) Place the compass inside the coil close to the eastern side and note the direction of the needle. Carry the compass from this point in a horizontal plane around this part of the coil, noting the direction of the needle at points S, E, and N of this part of the coil, successively.

(c) Next carry the compass in the same manner around the western side of the coil, noting the direction of the needle at each of the four points E, N, W, and S, successively. Represent these

Current from E
to W on top.

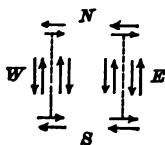


FIG. 33.

results and those of (a) and (b) by a diagram as in Fig. 33 (except that only that one of the two arrows shall be used which represents the true position of the needle at the several points). The dotted lines E and W represent sections of the coil in the horizontal plane traversed by the compass.

(d) Reverse the current through the galvanoscope and repeat (a), (b), and (c), and represent the results by a diagram.

(e) State your conclusion from your observations as follows: To a person looking along a conductor in the direction in which the current flows, the lines of magnetic force encircle the conductor in a direction (opposite to or the same as) that in which the turns of a corkscrew move when its point is propelled.

(f) Compare the diagrams obtained with those obtained in Exp. 68 when two magnets were placed parallel to each other, stating the likenesses and differences in the arrangement of the lines of force about the magnets and about the coil.

(g) State any indications that you may observe that the coil traversed by a current acts like a magnet having one pole at one the coil and the other pole at the other face.

DIRECTIONS FOR USING A GALVANOSCOPE OR GALVANOMETER AND A POLE-CHANGER.

The galvanoscope (Fig. 30) contains a coil so constructed that the entire coil of fifteen turns may be used or one of five turns or one of ten turns, as is best suited to the conditions under which it is used. The galvanometer *G* (Fig. 34) has an astatic needle. The galvanometer should be placed near the edge of the table where you stand; other apparatus connected therewith must give place to this. Short, flexible wires should be inserted in the screw-cups of the galvanometer and should not be removed while experimenting.

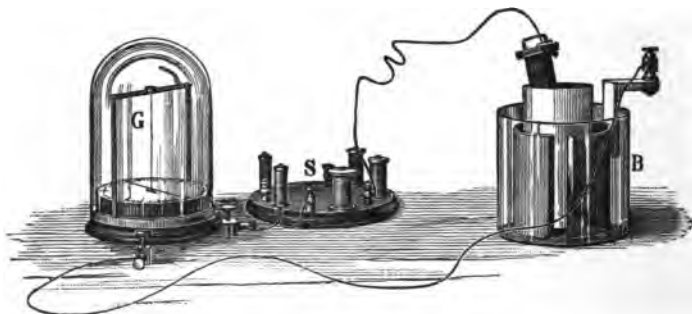


FIG. 34.

To "set the galvanometer," rotate it slowly and carefully until the needle points exactly to zero at each extremity. Care must be exercised that no article containing iron or steel is located near the galvanometer.

The current-bearing wires leading to and from the galvanometer should be kept near each other and in the same vertical planes with the turns of wire in the coil of the galvanometer, and should never be allowed to come near to the needle.

In taking observations on the galvanometer there are two errors which must be especially guarded against, viz.: (1) Error of parallax; *i.e.* apparent displacement of the needle, due to looking obliquely down upon it. The observer should look vertically down upon the needle. (2) Error of parallelism; *i.e.*

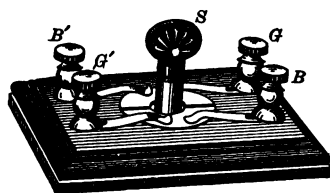


FIG. 35.

error arising from any departure from parallelism between the needle and the coils of the galvanometer. To correct this the current should be reversed through the galvanometer and a second set of readings made, and the mean between the two should be taken. For this purpose a pole-changer should be used. This is an instrument by which the current may be reversed, at will,

through any portion of the circuit outside the cell, or through any instrument in the circuit.

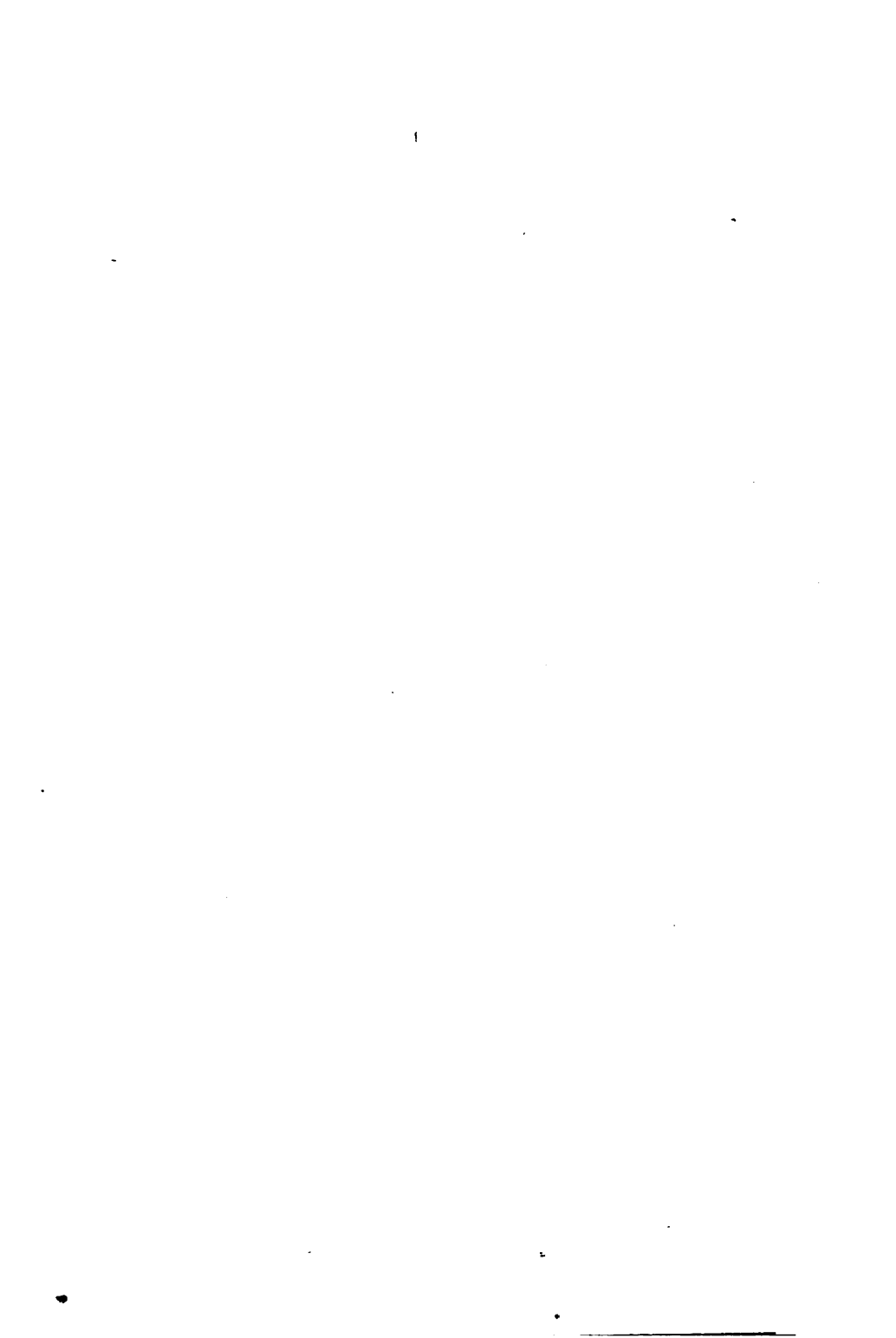


Fig. 35 represents a pole-changer introduced into a circuit in such a manner that the current can be sent, at will, either way through the galvanometer *G*.

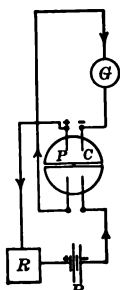


FIG. 36.

The circuit being opened at any suitable point, the two electrodes are introduced into the two screw-cups *B* and *B'*. Wires are then led from the screw-cups *G* and *G'* to the galvanometer.

With the assistance of the diagram (Fig. 36) it will be easy to trace the current from the battery *B* through the pole-changer *PC*, galvanometer *G*, and any other instrument *R*, back to the battery. By turning *S* (Fig. 35) through a quarter of a revolution the current through the galvanometer is reversed, as will appear on examination of Fig. 37.

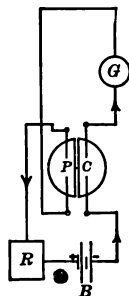


FIG. 37.

74 [Ex. XLIV].

App.: Daniell cell, pole-changer, galvanoscope (Fig. 30), rheostat (*R*, Fig. 38), and set of spools (*S*, Fig. 34).

(a) Join in series the cell, pole-changer *PC* (see directions for use of pole-changer, p. 65), galvanoscope, and the wires 1 and 2 of the rheostat. [Each of these German silver wires is a little more than a meter long and of the size No. 30. They may be electrically connected at any point by the sliding connectors *S*.] Set the connectors 1^m above the screw-cups 1 and 2, so that the current will pass through 2^m of G.S. wire. Read the deflection in *G*, reverse the current, read again, and record the average reading.

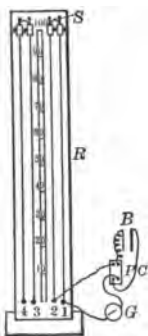


FIG. 38.

Move the connectors down to 90, so that the current will traverse 180^{cm} of G.S. wire, and again obtain and record an average reading.

Move the connectors successively down to 80, 70, 60, 50, 40, and 30, so that the current will traverse respectively 160, 140, 120, 100, 80, and 60^{cm} of G.S. wire. Obtain average readings in every case and record as follows :

KIND OF WIRE.	SIZE OF WIRE.	LENGTH OF WIRE. cm.	AVERAGE DEFLECTION.

(b) Shift the leading wires from screw-cups 1 and 2 to cups 3 and 4, and repeat all the above with these wires. [These wires are G.S. No. 28.]

(c) Shift the leading wires from cups 3 and 4 to the cups at the terminals of spool 4 of the set of spools. [This spool contains 14.6^m (16 yd.) of *copper* wire.]

(d) Inspect your measurements and state in general any relation you may discover between the length of a conductor and its resistance. State why, if any proportionality exists between these quantities, your measurements should not show it.

(e) Determine approximately from your tabulation what length of No. 30 G.S. is equivalent in resistance to 2^m of No. 30 G.S. wire.

(f) (1) If the area of the cross section of No. 30 wire be 1, the area of cross section of No. 28 wire is about 1×1.46 . Find the following quotients: $\frac{2 \text{ (meters No. 28 G.S. wire)}}{1.46}$ and $\frac{\text{length of No. 30 G.S. wire of equivalent resistance}}{1}$. (2) Are the

quotients nearly equal? If so, what relation should you infer exists between the area of cross section of wire and its resistance?

(g) Determine from the tabulation what length of No. 30 G.S. wire is about equal in resistance to 14.6^m of No. 30 copper wire, and thereby determine the specific resistance of German silver as compared with copper.

75 [Ex. XLV].

App.: 2 Daniell cells (same as used in Exp. 70), also an additional strip of copper ($10^{\text{cm}} \times 1^{\text{cm}}$) with wire attachment, galvanoscope, pole-changer, and resistance box.¹

(a) Set up a cell, using the small copper plate. [The liquids should be at the same depth in both cells, and the cells should stand a few minutes before using, so as to allow time for the liquids to penetrate the pores of the porous cups.] Introduce into circuit in series the 10-turn coil of the galvanoscope and the pole-changer. Put the plates as far apart in the cell as practicable. Read the deflection, reverse the current, read again, and record the average reading. Tabulate results as follows:

CASE.	CELL WITH <i>small or large</i> PLATES.	PLATES <i>near TOGETHER</i> OR <i>far APART</i> .	CIRCUIT WITH <i>small or large</i> EXTERNAL RESISTANCE.	AVERAGE READING.
(a)	small	far	small	
(b)	"	near	"	
(c)	large	far	"	
(d)	"	near	"	
(e)	small	far	large	
(f)	"	near	"	
(g)	large	far	"	
(h)	"	near	"	

(b) Move the plates as near each other as practicable, get the average reading as before, and record.

(c) Substitute the large copper plate for the small one. Set the plates far apart, get average reading, and record.

(d) Move the plates near each other, get average reading, and record.

(e) Introduce through the resistance box a resistance of 8 ohms into the circuit. Substitute the small copper plate for the large one. Set the plates far apart. Get average reading and record.

(f) Bring the plates near each other and find and record average reading.

(g) Substitute again the large copper plate for the small one, set the plates far apart, obtain and record average reading.

(h) Move the plates near each other and record average reading.

¹ See Fig. 390, author's "Principles of Physics," or Fig. 159, "Introduction to Physical Science."



(i) Critically examine your records and state whether they show the current to be more (or less) sensitive to changes in size and distance of the plates apart (i.e. to changes of internal resistance) when the external resistance is large than when it is small.

(j) How is the current-strength affected by the size and nearness of the plates? Why?

76 [Ex. XLV].

App.: same as in Exp. 74.

(a) Join in *multiple arc* two Daniell cells, each having a large copper element. Introduce into the circuit with this battery the resistance box, the pole-changer, and the 10-turn coil of the galvanoscope. With the resistance box throw a resistance of 8 ohms into the circuit. Read the deflection, reverse the current, read the deflection again, and record the average reading. Tabulate results as follows:

CASE.	CELLS JOINED IN.	EXTERNAL RESISTANCE.	AVERAGE READING.
(a)	arc	large	
(b)	"	small	
(c)	series	large	
(d)	"	small	

(b) Reduce the resistance in the resistance box to zero. Read, reverse, read again, and record the average reading.

(c) Join the two cells in *series*, leaving all other instruments in circuit as before. Throw a resistance of 8 ohms into circuit as in (a). Get the average reading as hitherto.

(d) Reduce the resistance in the resistance box to zero. Get the average reading.

(e) State, judging from your results in Exps. 75 and 76, under what conditions it is better to connect cells in series, and under what conditions it is better to connect cells in multiple arc.

77.

App.: Wheatstone bridge (Fig. 39), spools of wire, rheostat, galvanometer with astatic needle, and voltaic cell.

Measure resistances by use of the bridge. Carry the leading-out wires of the cell to the screw-cups BB' (Figs. 39 and 40); introduce the rheostat at RR , the unknown resistance (e.g. spool of wire) at xx , and the galvanometer into the bridge at GG .

Set the galvanometer so that the needle points to zero. Unplug 100 ohms in each branch (the other coils being all firmly plugged).

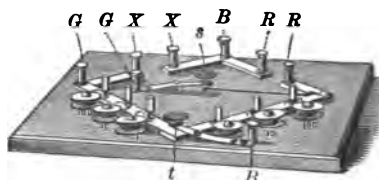


FIG. 39.

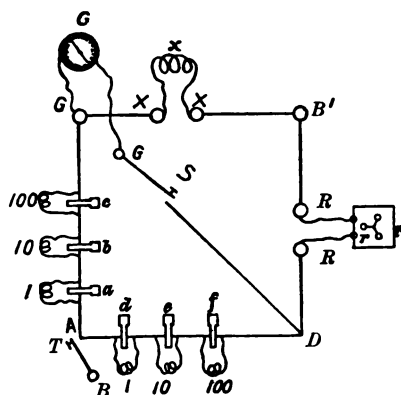


FIG. 40.

Close the circuit at T , then the bridge at S , and observe in what direction the needle is deflected when the switches of the rheostat are all on the zero studs. Next throw (say) 50 ohms (a resistance probably larger than the resistance to be measured) into the rheostat, close at T and S again, and notice the direction of the deflection. If the two deflections are in different directions, you infer that any subsequent deflection like the first will indicate too little resistance in the rheostat, and any deflection like the last will indicate too great resistance in the rheostat. Now regulate the resistance in the rheostat so

that on closing the bridge there will be no deflection of the needle. The resistance in the rheostat, then, is approximately the resistance sought. If this resistance is small, plug the 100's and unplug the 10's, and again regulate the resistance, if necessary, so that there will be no deflection.

It will be well generally, having learned by the first trial approximately what the unknown resistance is, to repeat the process by unplugging resistances in the bridge which are nearest the resistance being measured, as in that case the sensitiveness



of the galvanometer is greatest. The correctness of the results obtained with the bridge depends very largely upon the sensitiveness of the galvanometer.

If the same resistance be introduced between A and G as between A and D , it is evident that the resistance in r must be equal to the unknown resistance x ; hence the resistance of x may be read from r .

Tabulate results as follows :

NO. OF SPOOL.	NO. OF WIRE.	KIND OF WIRE.	LENGTH.	RESISTANCE.

78 [Harvard Ex.].

App.: an open coil of 20^m of No. 30 copper wire, cell, bridge, resistance box, galvanometer with astatic needle, Bunsen burner, and some vessel for heating water large enough to hold the coil, and a thermometer.

(a) In the vessel containing cold water suspend the coil and join it, the bridge, resistance box, and galvanometer in circuit with the cell in a suitable manner to measure the resistance of the coil. Suspend the thermometer in the water. Measure the resistance of the coil and take the temperature of the water.

(b) Apply heat to the water and keep the water stirring during the remainder of the experiment. At intervals of 5 minutes, until the water boils, measure the resistance of the coil and at each trial take the temperature of the water as soon as the measurement is completed. Record results as follows :

Resistance at temperature ° ohms.

" " " ° "

etc.

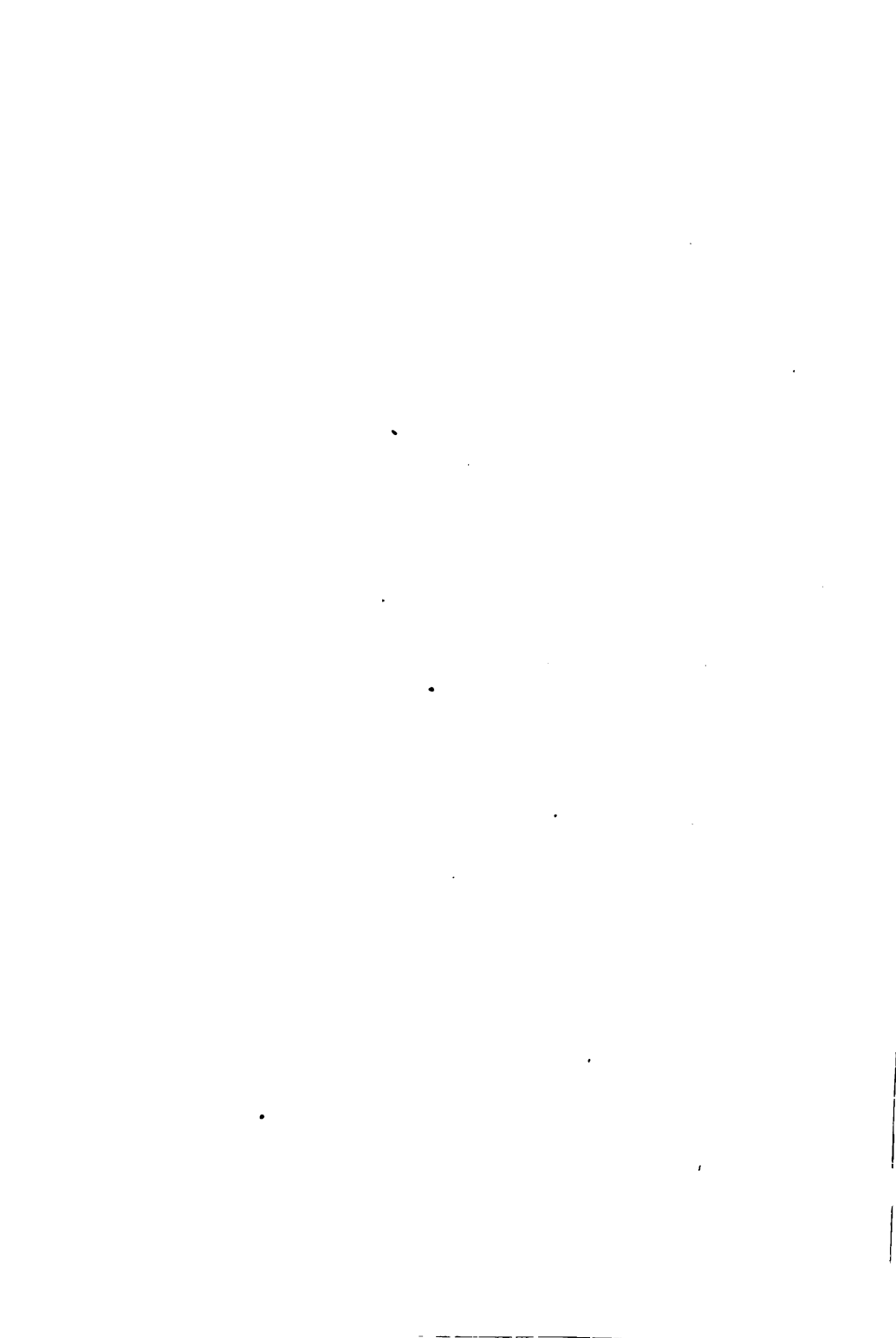
Rise in temperature = ... °

" (or fall) in resistance = ... ohms.

" " " " per degree of temperature = ... ohms.

Average increase (or decrease) per degree between

. . . . ° and ° = ... ohms.



79.

App.: cell, resistance box, bridge, and galvanometer.

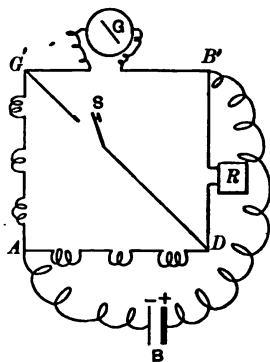


FIG. 41.

Measurement of galvanometer resistance.

Join instruments in circuit as in Fig. 41. Unplug resistances in the branches AG' and AD and vary the resistance in R until the deflection in the galvanometer G does not change when the key S is closed. Then $r = R \frac{a}{b}$, in which r is the resistance of the galvanometer, R is the resistance in the resistance box, and a and b are the resistances in the arms AG' and AD , respectively.

If $a = b$, then $r = R$.

81.





84 [Ex. XXX].

App.: field glasses, a pendulum consisting of a lead ball supported by a thread, a wooden support having a white pasteboard 30^{cm} square attached to the upright so as to render the swinging ball easily visible, and a bass drum.

(a) *To find the velocity of sound-waves in air.* [For two or more pupils.—To be performed out of doors on level ground.] By means of clamps suspend the pendulum from the wooden support with the bob in front of the pasteboard. Regulate its length (about 22 in.) so that it will make 80 single vibrations in a minute (or one vibration in $\frac{3}{4}$ of a second). Let the two pupils take positions about 750 ft. apart. One pupil sets the pendulum in vibration and beats the drum *precisely* at those instants when the pendulum reaches the side of the arc nearest him. The other pupil listens to the sounds as they reach his ear and watches the swinging ball with his glasses. The latter will move nearer or farther away as may be necessary till the sounds reach him at the instant the pendulum reaches the extremity of the arc opposite that at which the sounds are made. Ascertain the distance between the two stations when this occurs (*i.e.* the distance the sound-waves travel during one single vibration of the pendulum).

(b) Let the apparatus (but not the pupils) exchange places and repeat (a). Tabulate your results as follows :

DATA.

TRIAL.	DISTANCE TRAVELED.	WITH, AGAINST, OR ATEHWART THE WIND.	AVERAGE DISTANCE.	TIME OCCUPIED.
	ft.		ft.	sec.
1st	.....	..... }	.....	.....
2d	.....	..... }		.....

(c) Average the distance obtained in (a) and (b), and, from this average velocity per $\frac{3}{4}$ second, calculate the approximate velocity of sound-waves in air.

(d) What conditions of the air, not here taken into account, may affect the speed with which it is traversed by sound-waves ?

85 [Ex. XXXII].

App.: ring stand, glass funnel, rubber tube; glass tube about 18 in. long and 2 in. bore, having a cork (perforated by a small glass tube) inserted in one end (the whole arranged as in Fig. 42); measuring stick, centigrade thermometer, and a diapason whose vibration number is about 256 double vibrations per second.

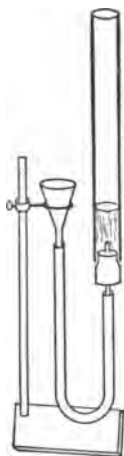


FIG. 42.

(a) Pour water into the funnel; set the diapason in vibration; hold it over and near the orifice of the tube *A*; raise or depress the tube until it gives the maximum reinforcement of sound; then place a rubber band at the surface of the water and measure from this point to the upper end of the tube. Add to this measurement one-fourth the diameter of the bore: the sum is one-fourth the wave-length produced by the diapason. Find the wave-length.

(b) Deduce from the equation,

$$\text{Wave-length} = \frac{\text{velocity}}{\text{vibration number}},$$

the velocity with which the air transmits sound.

(c) Verify the last result as follows: Take the temperature of the room; to 1090 ft. add 1.96 ft. for every degree above 0° C.

(d) Take the velocity as computed in (c), and, knowing the length of the resonant column, deduce the vibration rate or pitch of the diapason.

86 [Ex. XXXI].

App.: app. as shown in Fig. 43, bass-viol bow and lump of rosin, and a small porcelain evaporating dish in which to burn spirits of turpentine. [It is best that the glass plate be blackened with soot over the flame of burning turpentine by some experienced person and that several of these plates be prepared before the laboratory hour.]

(a) *To find the number of vibrations made by a fork in one second.* [For two pupils.] Regulate the length of the pendulum *P* (Fig. 43) so that the point of the fine steel pointer below the bob will just graze the glass plate *G* beneath it. Ascertain the number of vibrations made by the pendulum in (say) 5 seconds; one pupil counts while the other, watch in hand, times the counter. Count one for every double vibration. [The ear may assist the eye if a slip of paper ' ' ' so that every time the pendulum swings toward the

counter it will strike the paper and make a faint sound.] Several trials should be made and the average taken.

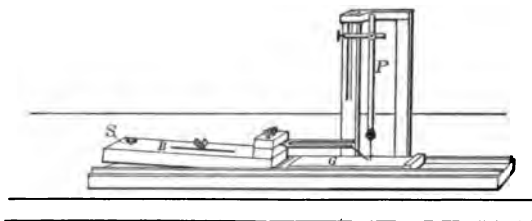


FIG. 43.

Next adjust the fork by means of the screw *S* (which, by elevating or depressing the board *B*, will tilt the fork up or down) so that the style, projecting obliquely from one of the tines, will very gently graze the glass plate, marking its path in the black deposit on the glass plate without wasting its energy thereby very rapidly.

Tighten the hair on the bow, rub the hair on the rosin, bow the fork strongly near the end of the tines, set the pendulum vibrating, and, quickly but with tolerably uniform velocity, draw the frame holding the glass plate beneath the style. If successful, the markings of the two vibrating styles will

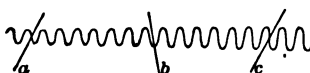


FIG. 44.

appear upon the smoked glass somewhat as represented in Fig. 44. Count the number of vibrations made by the fork (as depicted upon the glass plate) between two successive vibrations of the pendulum as *a* and *b* or *b* and *c*. Record as follows :

DATA.

Average number of double vibrations of pendulum in seconds
 " " " single " " " " " " " "
 Number of single vibrations of fork during single vibration of pendulum

RESULTS.

(*b*) Compute the time it takes the pendulum to make one single vibration.

(*c*) Compute the number of single vibrations made by the fork in one second.

87.

App.: 3 iron balls suspended at equal distances apart, two of them *A* and *B* (Fig. 45) by strings about 1^m long, so as to have the same vibration numbers; the other *C* about 5^{cm} shorter. At about $\frac{1}{2}$ their length from their points of suspension a taut thread connects them, being tied to them at points *a* and *b*, and attached at *c* by a wire hook.

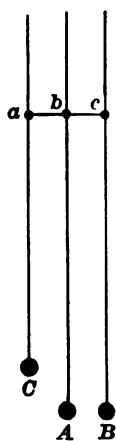


FIG. 45.

(a) Raise *A* (Fig. 45) a little way (not exceeding 25^{cm}) and let it swing; observe for a considerable time, and state the peculiarities of the vibrations caused in *B* and *C* by the periodic impulses communicated to them from *A* through the thread.

(b) State clearly the nature and cause of sympathetic and forced vibrations, as shown by this experiment.

(c) Disconnect the thread at *c*, raise both *A* and *C*, and set both in vibration at the same instant. Watch in hand, note the number of seconds which intervene between the start and the instant when the two balls first pass the centers of their arcs in opposite directions. Next note the interval which elapses from this instant until the two balls reach the extremities of their arcs on the same side at the same time.

(d) During which of these periods of time is the mutually destructive interference on the increase?

(e) During which of these periods is the destructive interference on the decrease?

(f) When is the destructive interference greatest?

(g) When is the destructive interference least; or, in other words, the resultant effect of the two motions greatest?

(h) Suppose these two pendulums act simultaneously on the same body of air; when would the resulting condensation be the least? the greatest?

(i) Suppose the vibrations were frequent enough to produce sound-waves; at what instant would these sound-waves be most intense? least intense?



88 [Ex. XXXIII].

App.: sonometer, balance, metric micrometer calipers, and meter stick.

Show, other things being the same, that the vibration rate of a stretched string varies inversely as its length.

(a) Use two wires of the same size and stretch each with equal force. Pluck both wires in the middle; do both give the same note?

(b) Insert the bridge so as to divide one of the strings into two equal parts. Pluck one of the halves in the middle; what musical interval do you find between the note given and the note given by the other string? Inference.

(c) *Show, other things being the same, that the vibration rate varies as the square root of the stretching force.*

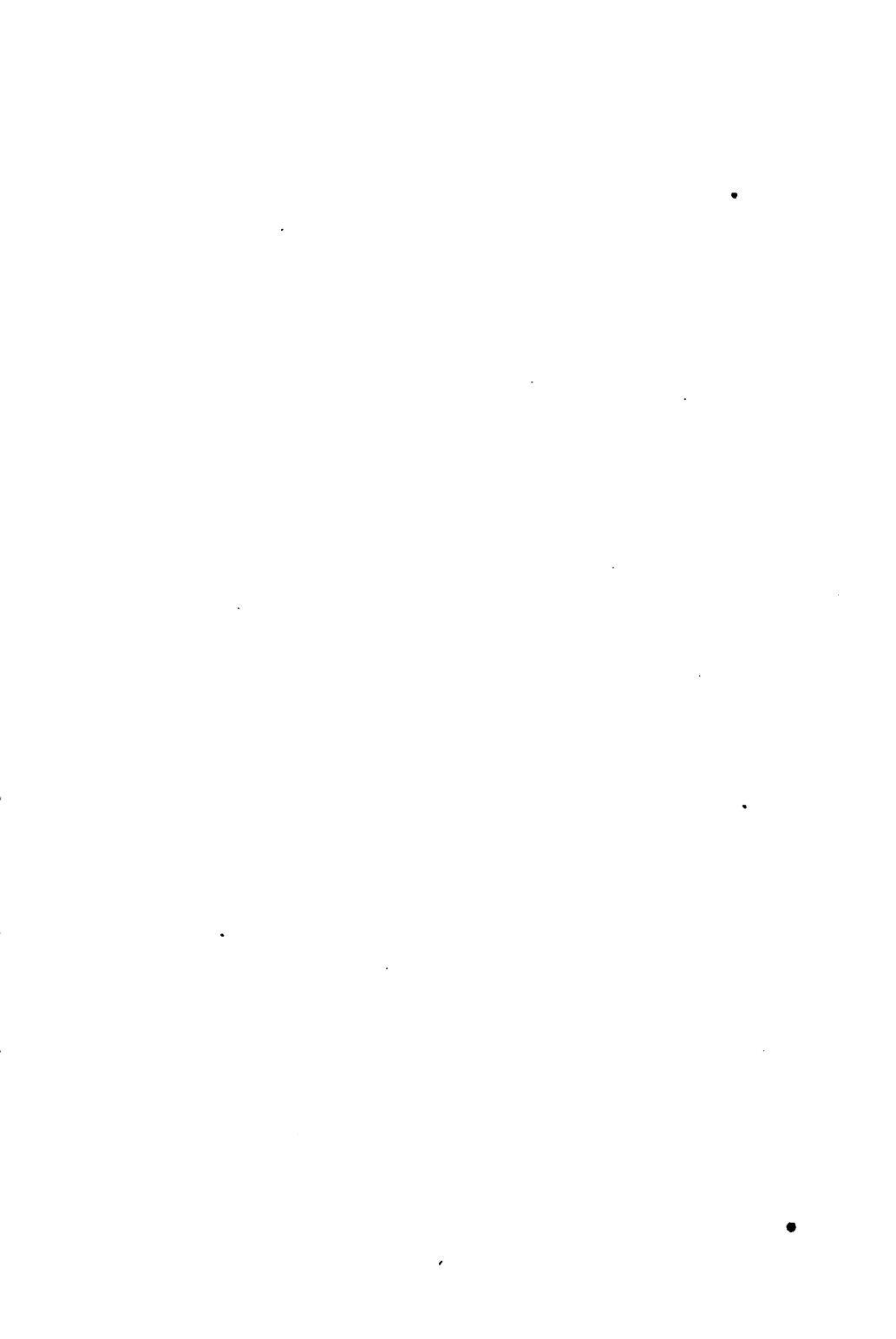
Take two similar wires and apply four times the stretching force to one that you do to the other. Pluck both; what musical interval is there between them? Inference.

(d) *Show, other things being the same, that the vibration rate varies inversely as the thickness of the wire, or as the square root of the weight of equal lengths of wire.*

Take two wires of different thicknesses and stretch them with equal forces. Place a bridge under the thicker wire and move it till it is brought into unison with the other. Let N and n represent the vibration numbers of the two wires, D and d their respective diameters, W and w weights of equal lengths, and L and l their lengths. Verify the following:

$$\frac{L}{l} = \frac{D}{d}.$$

Now $N : n :: \frac{1}{L} : \frac{1}{l}$; then $N : n :: \frac{1}{D} : \frac{1}{d}$; i.e. the vibration rate varies as the reciprocals of the diameters; in other words, *inversely as the diameters*. But $\frac{D}{d} = \frac{W}{w}$, or $\frac{D}{d} = \frac{\sqrt{W}}{\sqrt{w}}$; hence $N : n :: \frac{1}{\sqrt{W}} : \frac{1}{\sqrt{w}}$; i.e. the vibration rate varies inversely as the square roots of the weights.



•



90 [Ex. XXXIV].

App.: Bunsen photometer like that shown in Fig. 46 (or, better, Fig. 47, for description of which see author's "Principles of Physics," p. 328), and 5 spermaceti candles.

(a) *To find the relation between the intensity of illumination and the distance of the luminous body.* [For two pupils.—To be performed in a darkened room.] Place *A*, *B*, and *C* on the rail, with *A* between the other two, the extreme riders (say) 80 in. apart. Light candle after candle on *C*, noticing (1) whether the contrast between the greased circle and the surrounding ungreased surface

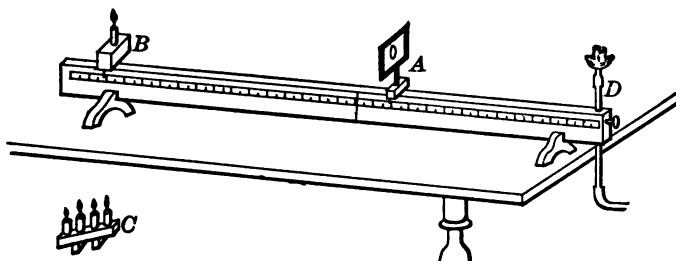


FIG. 46.

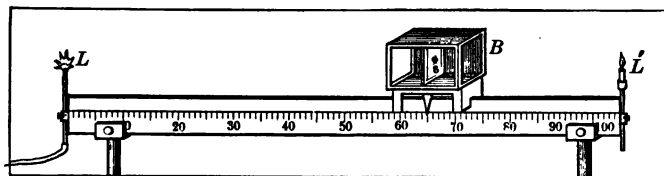
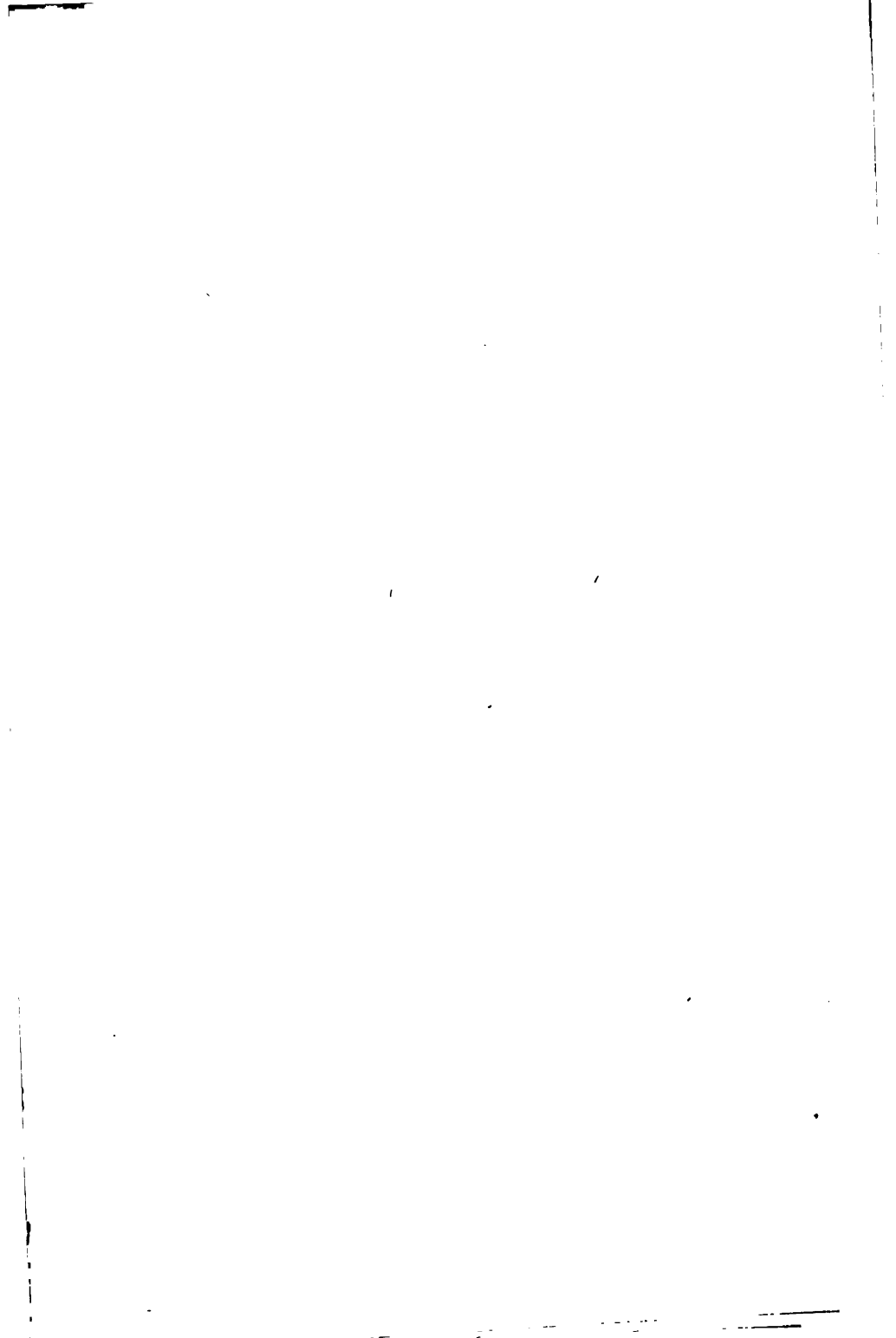


FIG. 47.

on the screen *A* is increased or decreased. (2) Is the circle lighter or darker than the surrounding surface on the side turned toward the lights? Explain fully the cause of the difference. (3) Is the circle lighter or darker than the rest of the surface on the side turned away from the lights? Explain.

(b) Light the candle on *B* and move *A* back and forth until the circle, viewed on both sides, appears illuminated, as nearly as practicable, the same as the surrounding surface. The observer should view the disk always at the same angle, *e.g.* 45° , and he should wait before taking observations until the candles have all



reached their normal condition of burning. Measure the distance of the screen *A* from both *B* and *C*, using the scale on the side of the rail and locating each rider by the points on the scale indicated by the needles beneath the riders.

(c) What relation do you infer exists between the distance of a luminous body from a screen and the intensity of its illumination?

91.

App.: same as in Exp. 90, a candle (preferably a standard candle), short piece of gas-pipe *D* (Fig. 46), terminating in a burner; several lava-tips of different delivery kept in small pasteboard boxes which are numbered.

Place the rider *B* containing a standard candle in position as far as practicable from *D*. Move *A* back and forth until the greased circle is least discernible on both sides or appears alike on both sides. Measure the distances *AD* and *AB*. From these distances compute the relative illuminating powers of the two flames; in other words, the candle power of the gas flame.

Use several tips and find the candle power yielded by each. Tabulate your results as follows :

TIP.	DIST. <i>AB</i> .	DIST. <i>AD</i> .	CANDLE POWER.
No. 1.			

[The State law of Massachusetts requires that "illuminating gas, when burning at the rate of five cubic feet per hour, under favorable conditions, as in an Argand burner, with proper air supply, should give out a light equivalent to that of at least fifteen candles." Less than this would indicate an inferior quality of gas.]



92 [Ex. XXXV].

App.: plane mirror 6 × 3 in., meter stick, sheet of paper 20 in. square, and a pin.

(a) Tack the paper at its corners upon a table and draw a straight line widthwise through the middle of it. Place the mirror and support it with a block on the middle of this line with its plane vertical and one of its long edges coincident with the line. Near one of the narrow edges of the paper draw a triangle (sides 5 to 8^{cm}). At one of its angles A stick a pin upright. Place the eye in such a position that it can see the image of the pin in the mirror along a straight edge of the meter stick, and draw a line on the paper representing this direction from the eye to the central or mirror line M . Letter this line aM . Place the eye in a different position and repeat, and letter this line $a'M$. Produce the two lines obtained by dotted lines back of the mirror line until they meet at a point A' , and thus find the virtual focus of the two rays emanating from A . In like manner find the virtual foci of rays emanating from each of the other angles B and C of the triangle. Letter the lines of reflection respectively bB and cC , and the virtual foci respectively B' and C' . Connect by straight lines the points A' , B' , and C' , and thereby construct the image of the triangle.

Draw lines from each of the points A , B , C , A' , B' , and C' to the mirror line and at right angles to it. Measure and record the following distances :

$$AM = \dots \text{ cm.}$$

$$BM = \dots \text{ "}$$

$$CM = \dots \text{ "}$$

$$A'M = \dots \text{ cm.}$$

$$B'M = \dots \text{ "}$$

$$C'M = \dots \text{ "}$$

Conclusions. [To be written on the sheet of paper.]

(b) (1) Regarding the relative size of object and image; (2) regarding the respective positions of object and image relative to the mirror; (3) whether the images of the pin are inverted, *i.e.* are upside down, with reference to the object; (4) whether the right side of the object is opposite the image of that side or opposite the image of the left side.

93.

App.: concave mirror, measuring stick, candle, and ring stand with clamp.

(a) *Find the focal length of a concave mirror.* Place a visiting-card in the clamp of the ring stand. Support the mirror with the stand so that, exposed to the direct rays of the sun on a clear day, it will throw a *circular* image of the sun upon the card. If the image is not a circle, it shows either that the rays do not fall upon the mirror parallel with its axis, or that the card has not a suitable inclination. Reduce the image to a minimum size (which should not exceed 3 or 4^{mm} diameter), by moving the card nearer the mirror or farther away, as the case may require. Then measure the distance of the card from the apex of the mirror.

(b) Why cannot the reflected rays be brought quite to a point?

(c) *Conjugate foci.* Place a candle flame at a little greater distance from the concave mirror than its focal length, so that its image will be thrown upon a screen not farther than 2^m from the

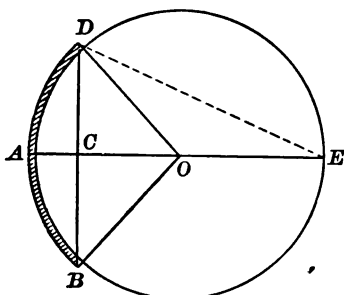


FIG. 48.

mirror. Then place the candle flame where the screen was, and place a small screen where the candle flame was. Are the object and image interchangeable? Why?

(d) Place the candle flame nearer the mirror than its principal focus. Describe in full the image formed.

(e) *Find the distance of the center of curvature of the mirror from its apex.* Measure its diameter *BD*

(Fig. 48); also its depth *CA*. There should be added to the latter the thickness of the glass, inasmuch as the posterior surface is the real mirror. The thickness may be measured approximately with the eye by placing on the anterior surface the point of a pencil and estimating the distance between this point and the image of this point. One-half of this distance is, approximately, the thickness of the glass.

By geometry, $\overline{CD}^2 = AC \times CE$; whence $CE = \frac{\overline{CD}^2}{AC}$.

$$AE = CE + AC. \quad AO = \frac{AE}{2}.$$



94 [Harvard Ex.].

App.: convex cylindrical mirror mounted on a semicircular support of wood (Fig. 49), a sheet of paper, a pin, and a straight-edged ruler.

(a) Place the mirror support on the sheet of paper with its straight edge parallel to and near to one edge of the paper. Draw around it on the paper a pencil mark. The result is a semicircle, except for a slight deviation due to the thickness of the mirror. At a distance of 5^{cm} from the front of the convex mirror and parallel to the straight edge of the support draw a straight



FIG. 49.

line 6^{cm} long, placing an arrowhead at one extremity. This arrow is to be regarded as the object. Mark the arrow point 1, the center of the line 2, and the other extremity 3. Stick the pin upright into one extremity of the line. Sight at the image of the pin along the straight edge of the ruler laid on the table and draw a line on the paper to represent the line of vision. Obtain in the same way another line of vision of widely different direction. Mark each of these lines with numbers corresponding to the number of the point in the object whose image is to be located. In a similar manner find lines of vision for each of the other two points of the object, and number the lines on the same plan.

Remove the mirror and produce each pair of lines till they meet. Connect by a line the three points thus found. This line is the image. Number the three points 1', 2', 3' to correspond to the numbers in the object, and locate the arrowhead in the image. Transfer your drawing to the blank page of your Manual.

(b) (1) Is the image larger or smaller than the object? (2) nearer or farther from the mirror than the object? (3) real or virtual? (4) straight or curved (if the latter, is the curvature in the same general direction as the curvature of the mirror or the reverse)?



95 [Harvard Ex.]

App.: same as in Exp. 94 and 2 straight slender splinters of wood.

(a) From two points *aa* (Fig. 51), 4ⁱⁿ apart on the front of the concave mirror draw on the mirror support two radii *rr* to the center of curvature *C*. Draw arrows *A* and *B* respectively 8ⁱⁿ and 15ⁱⁿ distant from the mirror front, and arrow *D* 15ⁱⁿ from *C*.

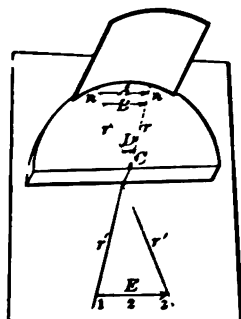


FIG. 50.

Hold the mirror about 10 in. from the eye and look at the images of the three arrows *A*, *B*, and *D*. (1) Does each of the three images point from left to right as do the arrows themselves? (2) Are the images of *A* and *B* longer or shorter than the arrows themselves?

(b) Stick a pin upright into the center of *A* and lay the splinters at a wide angle with each other so that each shall point toward the image of the pin, and in this way locate the position of the image.

(1) Is the image behind or in front of the mirror? (2) Is it a real or a virtual image?

(c) In the same manner locate the images of *B* and *D* and answer the same questions relating to their respective images.



96 [Harvard Ex.].

App.: same as in Exp. 94.

(a) Place the mirror on a sheet of paper as shown in Fig. 50. Produce the radial lines rr by the lines $r'r'$ drawn on the paper. Draw arrow E 6 to 8^{cm} from C . Locate the image of each of the points 1, 2, and 3, as in Exp. 94 with the convex mirror, drawing upon the paper the lines of vision, numbering them appropriately, and also drawing the image and numbering its three points. Transfer the drawing, including a tracing of the mirror support, as in Exp. 94, to the opposite blank page.

(b) Give a verbal description of the image, including its kind, location, whether inverted or not, and whether larger or smaller than the object.



97 [Harvard Ex.].

App.: cylindrical glass jar filled with water to within .5^{mm} of the tooth of a brass partition, brass index, metric rule, and pencil compass.

(a) *Do not move the jar or disturb its surface so as to wet the end of the index tooth in the partition.* With the eye about 25^{cm} from the edge of the jar, sight in a line with the edge of the jar and the lower edge of the tooth and adjust the index till its tip seems to lie in this line produced. Measure and record as follows :

Distance of lower edge of tooth below edge of jar cm.

" " tip of index below edge of jar cm.

Internal diameter of jar cm.

(b) Draw to suitable scale (*e.g.* 1^{cm} $\rightleftharpoons$ 2^{cm}) a vertical section of the interior of the jar, as in Fig. 51, making *DC* equal to the first of the measured distances given above, *OP* equal to the second distance, and *FG* equal to the third distance. Produce *DC* downwards by a dotted line. From *P* draw *PC* to represent the incident ray, and draw *CA* to represent the refracted ray. With any radius, as *CB*, and *C* as a center, describe an arc cutting the incident and refracted rays in points *I* and *B* respectively. From *I* drop the perpendicular *IE* on *DC* produced, and from *B* drop the perpendicular *BD* on *DC*.

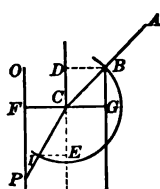


FIG. 51.

and refracted rays in points *I* and *B* respectively. From *I* drop the perpendicular *IE* on *DC* produced, and from *B* drop the perpendicular *BD* on *DC*.

(c) Measure to the tenth of a millimeter *IE* and *BD* and record the same.

State what the lines *IE* and *BD* respectively represent.

Fill the following ellipses :

$$\frac{IE}{DB} = \frac{\dots\dots}{\dots\dots} = \text{index of refraction from } \dots\dots \text{ to } \dots\dots$$

$$\frac{DB}{IE} = \frac{\dots\dots}{\dots\dots} = \text{ " " " " " " " }$$



99 [Ex. XXXVI].

App.: converging lens *C* (Fig. 52) 12 to 20^{cm} focal length and 4 to 6^{cm} diameter, meter stick, pasteboard screen *S*, and mounted pin *N*.

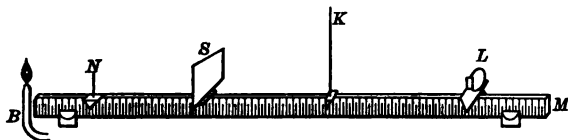
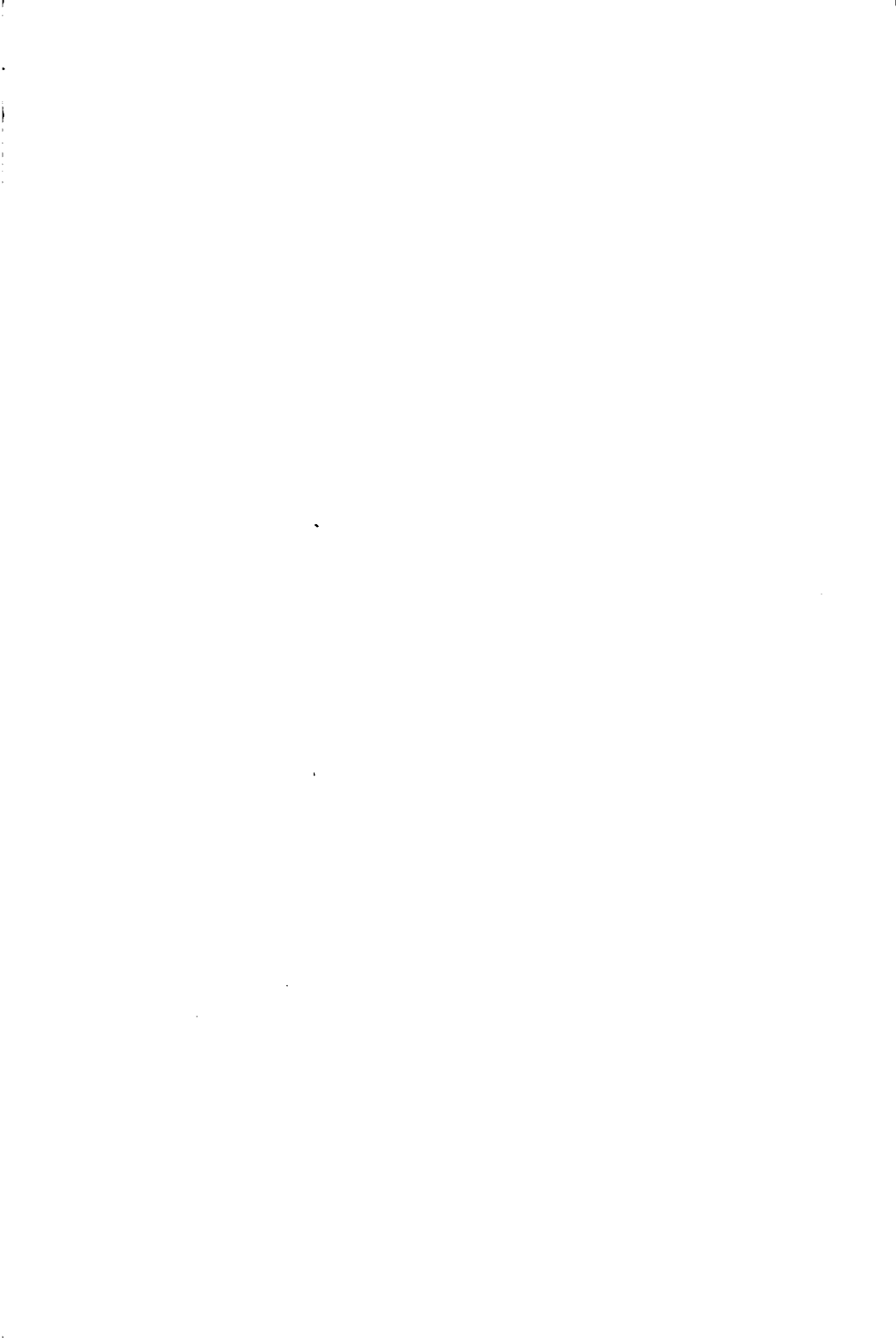


FIG. 52.

(a) *To find the focal length of a converging lens. First method.* [For two pupils.] Mount the lens upon the meter stick *M* at (about) the 90^{cm} mark and the screen *S* at (about) the 50^{cm} mark. With the screen between the sun and your eye, aim the stick at the sun so that the sun's rays passing through *L* may fall upon *S*. Slide *S* (or *L*) back and forth upon *M* until a sharp, distinct image of the sun is formed upon *S*. Measure the distance from the center of the lens to the screen. Reset *C* and *S* and repeat the measurements twice, and take the average of the three measurements for the focal length of the lens.

(b) *Second method.* Substitute the needle *N* for *S*, placing it at a distance from the end of *M* equal to the "distance of distinct vision" (with the normal eye from 22^{cm} to 25^{cm}). Hold this end of *M* near the eye, look through the lens (placed at first near the other end of *M*) at some distant object, as a church spire or the top of a flagstaff, and adjust the lens so that an inverted and distinct image of the object will be seen near and above *N*. (During the observation *M* should rest upon some steady support.) Move the eye sidewise, to and fro, watching *N* and the image. The more distant of the two will appear to move with the eye. Adjust *L* until this test fails or until both the image and *N* appear to move in the same direction. Measure the distance of *N* from *L*. Repeat twice, and take the average of the three measurements for the focal length of the lens.

(c) Why, in the *second method*, should the object viewed be several hundred feet distant? Which method is theoretically the more accurate? Why?



100 [Ex. XXXVII].

(a) *Conjugate foci of converging lens. Real foci.* Mount S (Fig. 52) upon M at (say) the 98^{cm} mark, and support the burner B 2^{cm} beyond the other end of M and so that the center of the flame shall be on the same horizontal level with the center of the lens. (B is a glass tube drawn out at one end so as to give a long, narrow flame. The flame should be reduced, by turning the gas stop-cock, to about 2.5^{cm} length.) Mount L near B and move it toward S until a distinct image of the flame appears upon S . Make measurements and record as indicated below. Without moving B or S , slide L nearer S and, if in another position L throws upon the screen a distinct image, measure and record as before.

(b) Place S (say) 80^{cm} from B . (If the distances here suggested do not suit the lens, other distances must be chosen. It may be necessary to join two meter sticks end to end.) Repeat the above, measure, and record as before.

(c) Repeat the above, placing S 60^{cm} or 120^{cm} from B .

DATA.

Let p and p' represent respectively the distances of the object and its image from the lens, and f the focal length (found in Exp. 90) of the lens.

$$(1) \ B \text{ and } S \ 100^{\text{cm}} \text{ apart} \quad \begin{cases} p = \dots \text{ cm.} \\ p' = \dots \text{ " } \\ p = \dots \text{ " } \\ p' = \dots \text{ " } \end{cases}$$

$$(2) \ B \text{ and } S \dots \text{ cm. apart} \quad \begin{cases} p = \dots \text{ cm.} \\ p' = \dots \text{ " } \\ p = \dots \text{ " } \\ p' = \dots \text{ " } \end{cases}$$

$$(3) \ B \text{ and } S \dots \text{ cm. apart} \quad \begin{cases} p = \dots \text{ cm.} \\ p' = \dots \text{ " } \\ p = \dots \text{ " } \\ p' = \dots \text{ " } \end{cases}$$

(d) Compare in every case $\frac{1}{f}$ with $\frac{1}{p} + \frac{1}{p'}$ (expressing the reciprocals of the three quantities in decimals), thus :

$$\begin{array}{l} (1) \left\{ \begin{array}{l} \frac{1}{p} + \frac{1}{p'} = \dots \text{ cm. Focal length } \dots \text{ cm.} \\ \frac{1}{p} + \frac{1}{p'} = \text{ " } \text{ " } \text{ " } \text{ " } \text{ " } \text{ " } \end{array} \right. \\ (2) \left\{ \begin{array}{l} \text{ " } = \text{ " } \text{ " } \text{ " } \text{ " } \text{ " } \text{ " } \end{array} \right. \\ (3) \left\{ \begin{array}{l} \text{ " } = \text{ " } \text{ " } \text{ " } \text{ " } \text{ " } \text{ " } \end{array} \right. \end{array}$$

- (e) (1) *General conclusion* (here state the relation between the reciprocals of object distance, image distance, and focal length of the lens). (2) How does p compare with f in the above cases? (3) Does p vary *as* or *inversely as* p' ?

101 [Ex. XXXVII].

(a) *Virtual foci.* Mount L about 2^{cm} from end of M , N a little beyond, and K (a knitting needle) near the other end of M . Looking through L , adjust N so that a distinct image of it, of maximum size, is seen. Then locate the image by so adjusting K that the images of N seen through the lens, and K seen *over* the lens, shall appear to lie in the same vertical line (or until they answer to the test given in Exp. 99).

[Caution: Keep both N and K vertical and in the same vertical plane with the center of L . More satisfactory results are obtained when the apparatus is directed to some near flat surface, *e.g.* a vertical side of a box.]

DATA.

$$p = \dots \text{ cm.} \quad p' = \dots \text{ cm.}$$

$$\text{Compare } \frac{1}{p} - \frac{1}{p'} = \dots \text{ cm. with } \frac{1}{f} = \dots \text{ cm.}$$

- (b) *General conclusion* (as in Exp. 100). How does p compare with f in this case?

102 [Ex. XXXVIII].

App.: lens, sheet of white paper about 100×40 cm, meter rod, and pins.

(a) *Real image.* Tack the paper at its corners upon the table. Draw a line connecting the middle points of the two ends of the paper. Near one end of this line draw another line at right angles to this and extending 4 cm on each side, and place an arrowhead at one end of the line last drawn. Divide this arrow into four equal parts, marking the division dots respectively 1, 2, 3, etc. Place the lens with its edge on the median line and its axis parallel with the line at a point distant from the middle of the arrow about 1.5 times the focal length of the lens.

Stick a pin upright into the point of the arrow (No. 1). Look through the lens from a distance and discover a distinct inverted image of the pin. Then locate this image by sticking another pin in the paper coincident with the image. This pin must be moved toward or from the lens until the image stands directly over the pin, and on moving the eye laterally both image and pin move together in the same direction. Mark this point I_1 . In the same way locate I_2 , I_3 , etc., corresponding to points 2, 3, etc., of the arrow. The five points outline the image of the arrow. Mark the point directly under the center of the lens L . Draw lines connecting each of the points 1, 2, 3, etc., of the arrow with its corresponding I -point. Measure and record the distance of each object-point from the lens, also the distance of each image-point from the lens. Record as follows:

$1L = \dots \text{ cm.}$	$LI_1 = \dots \text{ cm.}$
$2L = \dots \text{ cm.}$	$LI_2 = \dots \text{ cm.}$
etc.	etc.

Measure the length of the arrow and that of the image. If the latter be not a straight line, measure the distance straight from I_1 to I_5 ; if it be curved, measure, for the image distance from the lens, to the chord subtending the arc.

RESULTS.

(b) See whether a proportion (approximate) can be made of the following quantities, viz.: $3L : LI_3 :: \text{length of object} : \text{length of image}$.

(c) Repeat, substituting $1L$ and L_1 for $3L$ and LI_3 , respectively.

(d) State any law that you may have discovered.

103 [Ex. XXXIX].

App.: similar to that used in Exp. 102.

(a) *Virtual image.* Draw a median line as in last experiment. Place the lens about 20^{cm} from one end of this line. Still further along this line and at a distance from the lens equal to about two-thirds its focal length draw an arrow 5^{cm} long. Then proceed to locate the virtual image of the arrow, in the manner that experience gained in Exps. 92 and 96 dictates.

(b) Test the proportionality of the corresponding dimensions of the object and image to the respective distances of the same from the lens.

104.

App.: convex lens (Fig. 53) covered on one side with a card containing holes about 8mm diameter, arranged as in Fig. 54, paper or cardboard screen, and metric rule.

(a) *Spherical and chromatic aberration.* Place the lens with the covered side turned toward the sun (or distant gas flame), so that the rays will fall upon it as nearly parallel with the axis as possible. Place the card screen (Fig. 54) near the lens on the other side; move it slowly away until the elongated images of 1, 2, 3, and 4 meet at a point. Measure the distance of the screen at this point from the optical center of the lens.



FIG. 53.

(b) Make a drawing of the entire images formed by the eight holes.

(c) A portion of the light that passes through 1, 2, 3, and 4 is now brought to the same focus; why is not all the light from these holes brought to a focus?

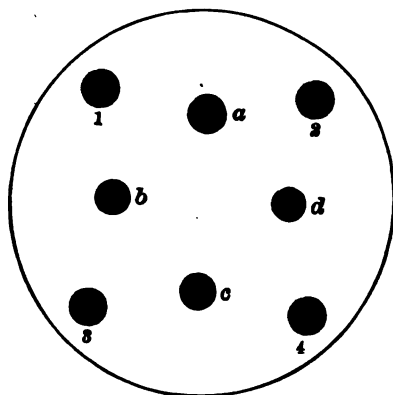


FIG. 54.

(d) Is there any evidence of dispersion of the light which passes through 1, 2, 3, and 4? If so, what is the evidence? What technical name is given to this phenomenon?

(e) Move the screen still farther from the lens until the light from a, b, c, and d meets at the same focus. Does any of the light from 1, 2, 3, and 4 meet at this focus? Why is

not the light from all the holes brought to a focus? What name is given to this phenomenon?

(f) Make a drawing of the several images as they now appear upon the screen.

105.

App.: refracting telescope, meter stick, and a visiting-card.

(a) *Determine approximately the magnifying power of the telescope.* Place the meter stick and card in a vertical position against a wall or board,

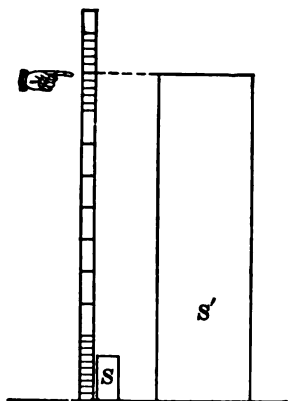


FIG. 55.

with the bottom of the stick and card on the same horizontal level. Stand 50 to 200 ft. away from them. After properly focussing the telescope so as to see the card, look at it through the telescope with the right eye; at the same time look at the card with the left eye (not through the telescope, of course). Let another person run his finger up and down the stick until it seems (to the left eye) to be on a level with the top of the image of the card (as seen with the right eye). Ascertain the apparent height (H) of the image S' (Fig. 55); also the height (h) of the card S . Let m = the magnifying power sought; then

$$m = \frac{H}{h}.$$

It is very important that the telescope be firmly supported upon some immovable object during this experiment.

(b) View objects near and far away, and observe whether the eye-glass must be nearer to or farther away from the object-glass when the object is near, in order to properly focus the image to the eye. Explain.

106.

App.: concave mirror, convex lens, and some object, e.g. a bouquet of artificial flowers of various colors.

(a) *Reflecting telescope.* Place the object from 3^{cm} to 6^{cm} from the mirror and a little to one side of the axis of the mirror. Standing a little on the other side of the axis, place the lens between yourself and the image, and focus it so that you will see the image distinctly through the lens. Describe the image as seen through the lens.

(b) What are the essential parts of a reflecting telescope, and what is the office of each part?



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